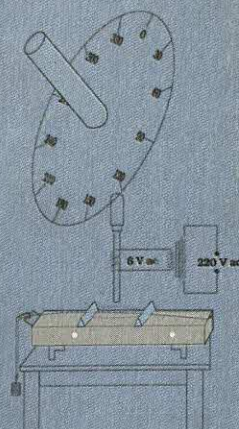
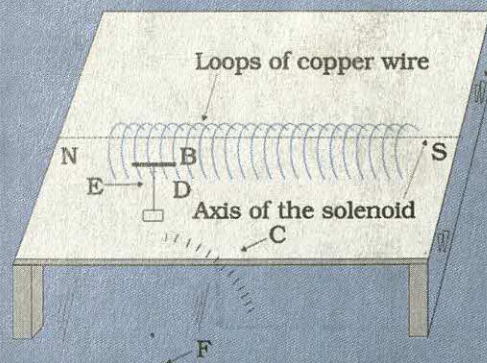
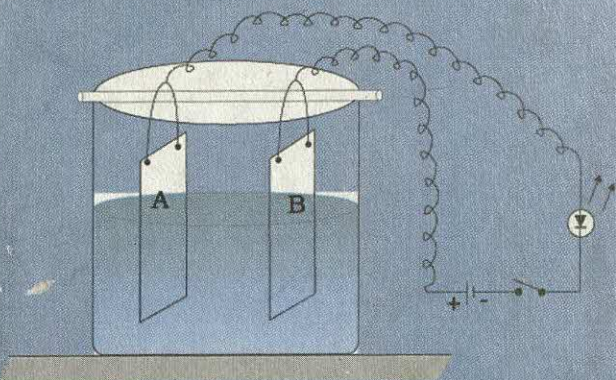


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PHYSICS



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Laboratory Manual

PHYSICS

Class XII

विद्यया ऽ मृतमश्नुते



एन सी ई आर टी
NCERT



राष्ट्रीय शैक्षिक अनुसंधान और प्रशिक्षण परिषद्
NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING

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FOREWORD

The National Council of Educational Research and Training (NCERT) is the apex body concerning all aspects of refinement of School Education. It has recently developed textual material in Physics for Higher Secondary stage which is based on the National Curriculum Framework (NCF)–2005. NCF recommends that children's experience in school education must be linked to the life outside school so that learning experience is joyful and fills the gap between the experience at home and in community. It recommends to diffuse the sharp boundaries between different subjects and discourages rote learning. The recent development of syllabi and textual material is an attempt to implement this basic idea. The present Laboratory Manual will be complementary to the textbook of Physics for Class XII. It is in continuation to the NCERT's efforts to improve upon comprehension of concepts and practical skills among students. The purpose of this manual is not only to convey the approach and philosophy of the practical course to students and teachers but to provide them appropriate guidance for carrying out experiments in the laboratory. The manual is supposed to encourage children to reflect on their own learning and to pursue further activities and questions. Of course, the success of this effort also depends on the initiatives to be taken by the principals and teachers to encourage children to carry out experiments in the laboratory and develop their thinking and nurture creativity.

The methods adopted for performing the practicals and their evaluation will determine how effective this practical book will prove to make the children's life at school a happy experience, rather than a source of stress and boredom. The practical book attempts to provide space to opportunities for contemplation and wondering, discussion in small groups, and activities requiring hands-on experience. It is hoped that the material provided in this manual will help students in carrying out laboratory work effectively and will encourage teachers to introduce some open-ended experiments at the school level.

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CONSTITUTION OF INDIA

Part IV A (Article 51 A)

Fundamental Duties

Fundamental Duties – It shall be the duty of every citizen of India —

- (a) to abide by the Constitution and respect its ideals and institutions, the National Flag and the National Anthem;
- (b) to cherish and follow the noble ideals which inspired our national struggle for freedom;
- (c) to uphold and protect the sovereignty, unity and integrity of India;
- (d) to defend the country and render national service when called upon to do so;
- (e) to promote harmony and the spirit of common brotherhood amongst all the people of India transcending religious, linguistic and regional or sectional diversities; to renounce practices derogatory to the dignity of women;
- (f) to value and preserve the rich heritage of our composite culture;
- (g) to protect and improve the natural environment including forests, lakes, rivers, wildlife and to have compassion for living creatures;
- (h) to develop the scientific temper, humanism and the spirit of inquiry and reform;
- (i) to safeguard public property and to abjure violence;
- (j) to strive towards excellence in all spheres of individual and collective activity so that the nation constantly rises to higher levels of endeavour and achievement;
- (k) who is a parent or guardian, to provide opportunities for education to his child or, as the case may be, ward between the age of six and fourteen years.



PREFACE

The development of the present laboratory manual is in continuation to the NCERT's efforts to support comprehension of concepts of science and also facilitate inculcation of process skills of science. This manual is complementary to the *Physics Textbook for Class XII* published by NCERT in 2007 following the guidelines enumerated in National Curriculum Framework (NCF)-2005. One of the basic criteria for validating a science curriculum recommended in NCF-2005, is that 'it should engage the learner in acquiring the methods and processes that lead to the generation and validation of scientific knowledge and nurture the natural curiosity and creativity of the child in science'. The broad objective of this laboratory manual is to help the students in performing laboratory based exercises in an appropriate manner so as to develop a spirit of enquiry in them. It is envisaged that students would be given all possible opportunities to raise questions and seek their answers from various sources.

The physics practical work in this manual has been presented under four sections (i) experiments (ii) activities (iii) projects and (iv) demonstrations. A write-up on major skills to be developed through practical work in physics has been given in the beginning which includes discussion on objectives of practical work, experimental errors, logarithm, plotting of graphs and general instructions for recording experiments.

Experiments and activities prescribed in the NCERT syllabus (covering CBSE syllabus also) of class XII are discussed in detail. Guidelines for conducting each experiment has been presented under the headings (i) apparatus and material required (ii) principle (iii) procedure (iv) observations (v) calculations (vi) result (vii) precautions (viii) sources of error. Some important experimental aspects that may lead to better understanding of result are also highlighted in discussion. Some questions related to the concepts involved have been raised so as to help the learners in self assessment. Additional experiments/activities related to a given experiment are put forth under suggested additional experiments/activities at the end.

A number of project ideas including guidelines are suggested so as to cover all types of topics that may interest young learners at higher secondary level.

A large number of demonstration experiments have also been suggested for the teachers to help them in classroom transaction. Teachers should encourage participation of the students in setting up and improvising apparatus, in discussion and give them opportunity to analyse the experimental data to arrive at conclusions.

Appendices have been included with a view to try some innovative experiments using improvised apparatus. Data section at the end of the book enlists a number of useful Tables of physical constants.

Each experiment, activity, project and demonstration suggested in this manual have been tried out by the experts and teachers before incorporating

them. We sincerely hope that students and teachers will get motivated to perform these experiments supporting various concepts of physics thereby enriching teaching learning process and experiences.

It may be recalled that NCERT brought out laboratory manual in physics for senior secondary classes earlier in 1989. The write-ups on activities, projects, demonstrations and appendices included in physics manual published by NCERT in 1989 have been extensively used in the development of the present manual.

We are grateful to the teachers and subject experts who participated in the workshops organised for the review and refinement of the manuscript of this laboratory manual.

I acknowledge the valuable contributions of Professor B.K. Sharma and other team members who contributed and helped in finalising this manuscript. I also acknowledge with thanks the dedicated efforts of Shashi Prabha who looked after the coordinatorship after superannuation of Professor B.K. Sharma in June, 2008. I also especially thank Professor Krishna Kumar, *Former Director* and Professor G. Ravindra, *Joint Director*, NCERT for their administrative support and keen interest in the development of this laboratory manual.

We warmly welcome comments and suggestions from our valued readers for further improvement of this manual.

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Part III (Articles 12 – 35)

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- before law and equal protection of laws;
- irrespective of religion, race, caste, sex or place of birth;
- of opportunity in public employment;
- by abolition of untouchability and titles.

Right to Freedom

- of expression, assembly, association, movement, residence and profession;
- of certain protections in respect of conviction for offences;
- of protection of life and personal liberty;
- of free and compulsory education for children between the age of six and fourteen years;
- of protection against arrest and detention in certain cases.

Right against Exploitation

- for prohibition of traffic in human beings and forced labour;
- for prohibition of employment of children in hazardous jobs.

Right to Freedom of Religion

- freedom of conscience and free profession, practice and propagation of religion;
- freedom to manage religious affairs;
- freedom as to payment of taxes for promotion of any particular religion;
- freedom as to attendance at religious instruction or religious worship in educational institutions wholly maintained by the State.

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- for protection of interests of minorities to conserve their language, script and culture;
- for minorities to establish and administer educational institutions of their choice.

Right to Constitutional Remedies

- by issuance of directions or orders or writs by the Supreme Court and High Courts for enforcement of these Fundamental Rights.
- 

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INTRODUCTION TO MAJOR SKILLS IN PHYSICS PRACTICAL WORK

I 1.1 | INTRODUCTION

The higher secondary stage is the most crucial and challenging stage of school education because at this stage the general undifferentiated curriculum changes into a discipline-based, content area-oriented course. At this stage, students take up physics as a discipline, with the aim of pursuing their future careers either in basic sciences or in science-based professional courses like engineering, medicine, information technology etc.

Physics deals with the study of matter and energy associated with the inanimate as well as the animate world. Although all branches of science require experimentation, controlled laboratory experiments are of central importance in physics. The basic purpose of laboratory experiments in physics, in general, is to verify and validate the concepts, principles and hypotheses related to the physical phenomena. Only doing this does not help the learners become independent thinkers or investigate on their own. In view of this, laboratory work is very much required and encouraged in different ways. These may include not only doing experiments but investigate different facets involved in doing experiments. Many activities as well as project work will therefore ensure that the learners are able to construct and reconstruct their ideas on the basis of first hand experiences through investigation in the laboratory. Besides, learners will be able to integrate experimental work with theory which they are studying at higher secondary stage through their environment.

The history of science reveals that many significant discoveries have been made while carrying out experiments. In the growth of physics, experimental work is as important as the theoretical understanding of a phenomenon. Performing experiments by one's own hands in a laboratory is important as it generates a feeling of direct involvement in the process of generating knowledge. Carrying out experiments in a laboratory personally and analysis of the data obtained also help in inculcating scientific temper, logical thinking, rational outlook, sense of self-confidence, ability to take initiative, objectivity, cooperative attitude, patience, self-reliance, perseverance, etc. Carrying out experiments also develop manipulative, observational and reporting skills.

The 'National Curriculum Framework' (NCF-2005) and the Syllabus for Secondary and Higher Secondary stages (NCERT, 2006) have therefore, laid considerable emphasis on laboratory work as an integral part of the teaching-learning process.

NCERT has already published *Physics Textbook for Classes XII*, based on the new syllabus. In order to supplement the conceptual understanding and to integrate the laboratory work in physics and contents of the physics course, this laboratory manual has been developed. The basic purpose of a laboratory manual in physics is to motivate the students towards practical work by involving them in "process-oriented performance" learning (as opposed to 'product-or result-oriented performance') and to infuse life into the sagging practical work in schools. In view of the alarming situation with regard to the conduct of laboratory work in schools, it is hoped that this laboratory manual will prove to be of considerable help and value.

I 1.2 OBJECTIVES OF PRACTICAL WORK

Physics deals with the understanding of natural phenomena and applying this understanding to use the phenomena for development of technology and for the betterment of society. Physics practical work involves '**learning by doing**'. It clarifies concepts and lays the seed for enquiry.

Careful and stepwise observation of sequences during an experiment or activity facilitate personal investigation as well as small group or team learning.

A practical physics course should enable students to do experiments on the fundamental laws and principles, and gain experience of using a variety of measuring instruments. Practical work enhances basic learning skills. Main skills developed by practical work in physics are discussed below.

I 1.2.1 MANIPULATIVE SKILLS

The learner develops **manipulative skills** in practical work if she/he is able to

- (i) *comprehend* the theory and objectives of the experiment
 - (ii) *conceive* the procedure to perform the experiment
 - (iii) *set-up* the apparatus in proper order
 - (iv) *check* the suitability of the equipment, apparatus, tool regarding their working and functioning
 - (v) *know* the limitations of measuring device and find its least count, error etc.
-

- (vi) *handle* the apparatus carefully and cautiously to avoid any damage to the instrument as well as any personal harm
- (vii) *perform* the experiment systematically
- (viii) *make* precise observations
- (ix) *make* proper substitution of data in formula, keeping proper units (SI) in mind
- (x) *calculate* the result accurately and express the same with appropriate significant figures, justified by the degree of accuracy of the instrument
- (xi) *interpret* the results, verify principles and draw conclusions
- (xii) *improvise* simple apparatus for further investigations by selecting appropriate equipment, apparatus, tools, materials.

I 1.2.2 O BSERVATIONAL SKILLS

The learner develops **observational skills** in practical work if she/he is able to

- (i) *read* about instruments and measure physical quantities, keeping least count in mind
- (ii) *follow* the correct sequence while making observations
- (iii) *take* observations carefully in a systematic manner
- (iv) *minimise* some errors in measurement by repeating every observation independently a number of times.

I 1.2.3 D RAWING SKILLS

The learner develops **drawing skills** for recording observed data if she/he is able to

- (i) *make* schematic diagram of the apparatus
- (ii) *draw* ray diagrams, circuit diagrams correctly and label them
- (iii) *depict* the direction of force, tension, current, ray of light etc, by suitable lines and arrows
- (iv) *plot* the graphs correctly and neatly by choosing appropriate scale and using appropriate scale.

I 1.2.4 R EPORTING SKILLS

The learner develops **reporting skills** for presentation of observation data in practical work if she/he is able to

- (i) *make* a presentation of aim, apparatus, formula used, principle, observation table, calculations and result for the experiment
- (ii) Support the presentation with labelled diagram using appropriate symbols for components
- (iii) *record* observations systematically and with appropriate units in a tabular form wherever desirable
- (iv) *follow* sign conventions while recording measurements in experiments on ray optics
- (v) *present* the calculations/results for a given experiment alongwith proper significant figures, using appropriate symbols, units, degree of accuracy
- (vi) *calculate* error in the result
- (vii) *state* limitations of the apparatus/devices
- (viii) *summarise* the findings to reject or accept a hypothesis
- (ix) *interpret* recorded data, observations or graphs to draw conclusion and
- (x) *explore* the scope of further investigation in the work performed.

However, the most valued skills perhaps are those that pertain to the realm of creativity and investigation.

I 1.3 SPECIFIC OBJECTIVES OF LABORATORY WORK

Specific objectives of laboratory may be classified as process-oriented performance skills and product-oriented performance skills.

I 1.3.1 PROCESS - ORIENTED PERFORMANCE SKILLS

The learner develops process-oriented performance skills in practical work if she/he is able to

- (i) *select* appropriate tools, instruments, materials, apparatus and chemicals and handle them appropriately.
- (ii) *check* for the working of apparatus beforehand
- (iii) *detect* and rectify instrumental errors and their limitations
- (iv) *state* the principle/formula used in the experiment
- (v) *prepare* a systematic plan for taking observations
- (vi) *draw* neat and labelled diagram of given apparatus/ray diagram/circuit diagram wherever needed

- (vii) *set up* apparatus for performing the experiment
- (viii) *handle* the instruments, chemicals and materials carefully
- (ix) *identify* the factors that will influence the observations and take appropriate measures to minimise their effects
- (x) *perform* experiment within stipulated time with reasonable speed, accuracy and precision
- (xi) *represent* the collected data graphically and neatly by choosing appropriate scale and neatly, using proper scale
- (xii) *interpret* recorded data, observations, calculation or graphs to draw conclusion
- (xiii) *report* the principle involved, procedure and precautions followed in performing the experiment
- (xiv) *dismantle* and reassemble the apparatus
- (xv) *follow* the standard guidelines of working in a laboratory.

I 1.3.2 P PRODUCT - ORIENTED PERFORMANCE SKILLS

The learner develops product-oriented performance skills in practical work if she/he is able to

- (i) *identify* various parts of the apparatus and materials used in the experiment
- (ii) *set-up* the apparatus according to the plan of the experiment
- (iii) *take* observations and record data systematically so as to facilitate graphical or numerical analysis
- (iv) *present* the observations systematically using graphs, calculations etc. and draw inferences from recorded observations
- (v) *analyse* and interpret the recorded observations to finalise the results and
- (vi) *accept or reject* a hypothesis based on the experimental findings.

I 1.4 E EXPERIMENTAL ERRORS

The ultimate aim of every experiment is to measure directly or indirectly the value of some physical quantity. The very process of measurement brings in some uncertainties in the measured value. THERE IS NO MEASUREMENT WITHOUT ERRORS. As such the value

of a physical quantity obtained from some experiment may be different from its standard or true value. Let 'a' be the experimentally observed value of some physical quantity, the 'true' value of which is ' a_0 '. The difference $(a - a_0) = e$ is called the error in the measurement. Since a_0 , the true value, is mostly not known and hence it is not possible to determine the error e in absolute terms. However, it is possible to estimate the likely magnitude of e . The estimated value of error is termed as **experimental error**. The error can be due to least count of the measuring instrument or a mathematical relation involving least count as well as the variable. The quality of an experiment is determined from the experimental uncertainty of the result. Smaller the magnitude of uncertainty, closer is the experimentally measured value to the true value. **Accuracy is a measure of closeness of the measured value to the true value.** On the other hand, if a physical quantity is measured repeatedly during the same experiment again and again, the values so obtained may be different from each other. This dispersion or spread of the experimental data is a measure of the precision of the experiment/instrument. A smaller spread in the experimental value means a more precise experiment. **Thus, accuracy and precision are two different concepts. Accuracy is a measure of the nearness to truth, while precision is a measure of the dispersion in experimental data.** It is quite possible that a high precision experimental data may be quite inaccurate (if there are large systematic errors present). A rough estimate of the maximum spread is related to the least count of the measuring instrument.

Experimental errors may be categorised into two types: (a) systematic and (b) random. Systematic errors may arise because of (i) faulty instruments (like zero error in vernier callipers), (ii) incorrect method of doing the experiment, and (iii) due to the individual who is conducting the experiment. **Systematic errors** are those errors for which corrections can be applied and in principle they can be removed. Some common systematic errors: (i) Zero error in micrometer screw and vernier callipers readings. (ii) The 'backlash' error. When the readings on a scale of microscope are taken by rotating the screw first in one direction and then in the reverse direction, the reading is less than the actual distance through which the screw is moved. To avoid this error all the readings must be taken while rotating the screw in the same direction. (iii) The 'bench error' or 'index correction'. When distances measured on the scale of an optical bench do not correspond to the actual distances between the optical devices, addition or subtraction of the difference is necessary to obtain correct values. (iv) If the relation is linear, and if the systematic error is constant, the straight-line graph will get shifted keeping the slope unchanged, but the intercept will include the systematic error.

In order to find out if the result of some experiment contains systematic errors or not, the same quantity should be measured by a different method. If the values of the same physical quantity obtained by two

different methods differ from each other by a large amount, then there is a possibility of systematic error. The experimental value, after corrections for systematic errors still contain errors. All such residual errors whose origin cannot be traced are called **random errors**. Random errors cannot be avoided and there is no way to find the exact value of random errors. However, their magnitude may be reduced by measuring the same physical quantity again and again by the same method and then taking the mean of the measured values. [For details, see *Physics Textbook for Class XI, Part-I Chapter 2* (NCERT, 2006)].

While doing an experiment in the laboratory, we measure different quantities using different instruments having different values of their least counts. It is reasonable to assume that the maximum error in the measured value is not more than the least count of the instrument with which the measurement has been made. As such in the case of simple quantities measured directly by an instrument, the least count of the instrument is generally taken as the maximum error in the measured value. If a quantity having a true value A_0 is measured as A with the instrument of least count a , then

$$\begin{aligned} A &= (A_0 \pm a) \\ &= A_0 (1 \pm a / A_0) \\ &= A_0 (1 \pm f_a) \end{aligned}$$

where f_a is called the maximum fractional error of A . Similarly, for another measured quantity B , we have

$$B = B_0 (1 \pm f_b)$$

Now some quantity, say Z , is calculated from the measured value of A and B , using the formula

$$Z = A.B$$

We now wish to calculate the expected total uncertainty (or the likely maximum error) in the calculated value of Z . We may write

$$\begin{aligned} Z &= A.B \\ &= A_0 (1 \pm f_a).B_0 (1 \pm f_b) \\ &= A_0 B_0 (1 \pm f_a \pm f_b \pm f_a f_b) \\ &\approx A_0 B_0 [1 \pm (f_a + f_b)], \text{ [If } f_a \text{ and } f_b \text{ are very small quantities, their} \end{aligned}$$

product $f_a f_b$ can be neglected]

$$\text{or } Z \approx Z_0 [1 \pm f_z]$$

where the fractional error f_z in the value of Z may have the largest value of $|f_a + f_b|$.

On the other hand, if the quantity Y to be calculated is given as

$$Y = A/B$$

$$= A_0 (1 \pm f_a) / B_0 (1 \pm f_b)$$

$$= Y_0 (1 \pm f_a) (1 \pm f_b)^{-1}; \quad \left[Y_0 = \frac{A_0}{B_0} \right]$$

$$= Y_0 (1 \pm f_a) (1 \pm f_b + f_b^2)$$

$$= Y_0 (1 \pm f_a) (1 \pm f_b)$$

$$\sim Y_0 [1 \pm (f_a + f_b)]$$

or $Y = Y_0 (1 \pm f_y)$, with $f_y = f_a + f_b$, where the maximum fractional uncertainty f_y in the calculated value of Y is again $|f_a + f_b|$. Note that the maximum fractional uncertainty is always additive.

Taking a more general case, where a quantity P is calculated from several measured quantities x, y, z etc., using the formula $P = x^a y^b z^c$, it may be shown that the maximum fractional error f_p in the calculated value of P is given as

$$f_p = |a|f_x + |b|f_y + |c|f_z$$

It may be observed that the value of the overall fractional error f_p in the quantity P depends on the fractional errors f_x, f_y, f_z etc. of each measured quantity, as well as on the power a, b, c etc., of these quantities which appear in the formula. As such, the quantity which has the highest power in the formula, should be measured with the least possible fractional error, so that the contribution of $|a|f_x + |b|f_y + |c|f_z$ to the overall fraction error f_p are of the same order of magnitude.

Let us calculate the expected uncertainty (or experimental error) in a quantity that has been determined using a formula which involves several measured physical parameters.

A quantity Y , Young's Modulus of elasticity is calculated using the formula

$$Y = \frac{MgL^3}{4bd^3\delta}$$

where M is the mass, g is the acceleration due to gravity, L is the length of a metallic bar of rectangular cross-section, with breadth b , and thickness d , and δ is the depression (or sagging) from the horizontal in the bar when a mass M is suspended from the middle point of the bar, supported at its two ends (Fig. I 1.1).

Now in an actual experiment, mass M may be taken as 1 kg. Normally the uncertainty in mass is not more than 1 g. It means that the least count of the ordinary balance used for measuring mass is 1 g. As such, the fractional error f_M is 1g/1kg or $f_M = 1 \times 10^{-3}$.

Let us assume that the value of acceleration due to gravity g is 9.8 m/s² and it does not contain any significant error. Hence there will be no fractional error in g , i.e., $f_g = 0$. Further the length L of the bar is, say, 1 m and is measured by an ordinary metre scale of least count of 1 mm = 0.001 m. The fractional error f_L in the length L is therefore,

$$f_L = 0.001 \text{ m} / 1 \text{ m} = 1 \times 10^{-3}.$$

Next the breadth b of the bar which is, say, 5 cm is measured by a vernier callipers of least count 0.01 cm. The fractional error f_b is then,

$$f_b = 0.01 \text{ cm} / 5 \text{ cm} = 0.002 = 2 \times 10^{-3}.$$

Similarly, for the thickness d of the bar, a screw gauge of least count 0.001 cm is used. If, a bar of thickness, say, 0.2 cm is taken so that

$$f_d = 0.001 \text{ cm} / 0.2 \text{ cm} = 0.005 = 5 \times 10^{-3}.$$

Finally, the depression δ which is measured by a spherometer of least count 0.001 cm, is about 5 mm, so that

$$f_\delta = 0.001 \text{ cm} / 0.5 \text{ cm} = 0.002 = 2 \times 10^{-3}.$$

Having calculated the fractional errors in each quantity, let us calculate the fractional error in Y as

$$\begin{aligned} f_Y &= (1)f_M + (1)f_g + (3)f_L + (1)f_b + (3)f_d + (1)f_\delta \\ &= 1 \times (1 \times 10^{-3}) + 1 \times 0 + 3 \times (1 \times 10^{-3}) + 1 \times (2 \times 10^{-3}) + 3 \times (5 \times 10^{-3}) + 1 \times (2 \times 10^{-3}) \\ &= 1 \times 10^{-3} + 3 \times 10^{-3} + 2 \times 10^{-3} + 15 \times 10^{-3} + 2 \times 10^{-3} \\ \text{or, } f_Y &= 22 \times 10^{-3} = 0.022. \end{aligned}$$

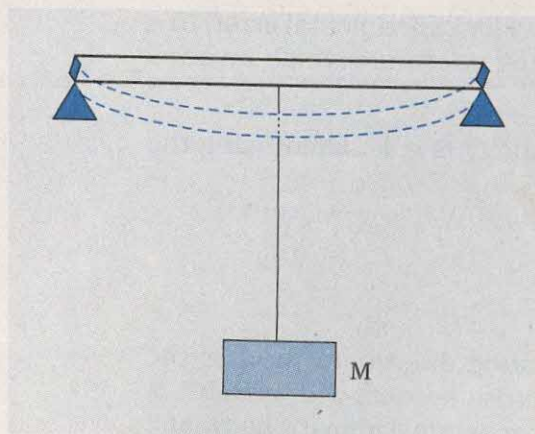


Fig. I 1.1 A mass M is suspended from the metallic bar supported at its two ends

Hence the possible fractional error (or uncertainty) is $f_y \times 100 = 0.022 \times 100 = 2.2\%$. It may be noted that, for a good experiment, the contribution to the maximum fractional error f_y in the calculated value of Y contributed by various terms, i.e., f_M , $3f_L$, f_b , $3f_d$, and f_δ should be of the same order of magnitude. It should not happen that one of these quantities becomes so large that the value of f_y is determined by that factor only. If this happens, then the measurement of other quantities will become insignificant. It is for this reason that the length L is measured by a metre scale which has a large least count (0.1 cm) while smaller quantities d and δ are measured by screw gauge and spherometer, respectively, which have smaller least count (0.001 cm). Also those quantities which have higher power in the formula, like d and L should be measured more carefully with an instrument of smaller least count.

The end product of most of the experiments is the measured value of some physical quantity. This measured value is generally called the result of the experiment. In order to report the result, three main things are required. These are – the measured value, the expected uncertainty in the result (or experimental error) and the unit in which the quantity is expressed. Thus the **measured value** is expressed along with the error and proper unit as the value $\pm$ error (units).

Suppose a result is quoted as $A \pm a$ (unit).

This implies that the value of A is estimated to an accuracy of 1 part in A/a , both A and a being numbers. It is a general practice to include all digits in these numbers that are reliably known plus the first digit that is uncertain. Thus, all reliable digits plus the first uncertain digit together are called SIGNIFICANT FIGURES. The significant figures of the measured value should match with that of the errors. In the present example assuming Young Modulus of elasticity, $Y = 18.2 \times 10^{10} \text{ N/m}^2$; (please check this value by calculating Y from the given data) and

$$\text{error, } \frac{\Delta Y}{Y} = f_y$$

$$\Delta Y = f_y \cdot Y$$

$$= 0.022 \times 18.2 \times 10^{10} \text{ N/m}^2$$

$$= 0.39 \times 10^{10} \text{ N/m}^2, \text{ where } \Delta Y \text{ is experimental error.}$$

So the quoted value of Y should be $(18.2 \pm 0.4) \times 10^{10} \text{ N/m}^2$.

I 1.5 LOGARITHMS

The logarithm of a number to a given base is the index of the power to which the base must be raised to equal that number.

If $a^x = N$ then x is called logarithm of N to the base a , and is denoted by $\log_a N$ [read as log N to the base a]. For example, $2^4 = 16$. The log of 16 to the base 2 is equal to 4 or, $\log_2 16 = 4$.

In general, for a number we use logarithm to the base 10. Here $\log 10 = 1$, $\log 100 = \log 10^2$ and so on. Logarithm to base 10 is usually written as log.

(i) COMMON LOGARITHM

Logarithm of a number consists of two parts:

- (i) Characteristic — It is the integral part [whole of natural number]
- (ii) Mantissa — It is the fractional part, generally expressed in decimal form (mantissa is always positive).

(ii) HOW TO FIND THE CHARACTERISTIC OF A NUMBER?

The characteristic depends on the magnitude of the number and is determined by the position of the decimal point. For a number greater than 1, the characteristic is positive and is less than the number of digits to the left of the decimal point.

For a number smaller than one (i.e., decimal fraction), the characteristic is negative and one more than the number of zeros between the decimal point and the first digit. For example, characteristic of the number

430700 is 5; 4307 is 3; 43.07 is 1;
4.307 is 0; 0.4307 is -1; 0.04307 is -2;
0.0004307 is -4 0.00004307 is -5.

The negative characteristic is usually written as $\bar{1}, \bar{2}, \bar{4}, \bar{5}$ etc and read as bar 1, bar 2, etc.

I 1.5.1 HOW TO FIND THE MANTISSA OF A NUMBER?

The value of mantissa depends on the digits and their order and is independent of the position of the decimal point. As long as the digits and their order is the same, the mantissa is the same, whatever be the position of the decimal point.

The logarithm tables given at the end of the book give the mantissa only. They are usually meant for numbers containing four digits, and if a number consists of more than four figures, it is rounded off to four figures after determining the characteristic. To find mantissa, the tables are used in the following manner :

- (i) The first two significant figures of the number are found at the extreme left vertical column of the table wherein the number lying between 10 and 99 are given. The mantissa of the figures which are less than 10 can be determined by multiplying the figures by 10.
- (ii) Along the horizontal line in the topmost column the figures

0	1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---	---

are given. These correspond to the third significant figure of the given number.

- (iii) Further right column under the figures (digits) corresponds to the fourth significant figures.

1	2	3	4	5	6	7	8	9
---	---	---	---	---	---	---	---	---

Example 1 : Find the logarithm of 278.6.

Answer : The number has 3 figures to the left of the decimal point. Hence, its characteristic is 2. To find the mantissa, ignore the decimal point and look for 27 in the first vertical column. For 8, look in the central topmost column. Proceed from 27 along a horizontal line towards the right and from 8 vertically downwards. The two lines meet at a point where the number 4440 is written. This is the mantissa of 278. Proceed further along the horizontal line and look vertically below the figure 6 in difference column. You will find the figure 9. Therefore, the mantissa of 2786 is $4440 + 9 = 4449$.

Hence the logarithm of 278.6 is 2.4449 (or $\log 278.6 = 2.4449$).

Example 2 : Find the logarithm of 278600.

Answer : The characteristic of this number is 5 and the mantissa is the same as in Example 1, above. We can find the mantissa of only four significant figures. Hence, we neglect the last 2 zero.

$$\therefore \log 278600 = 5.4449$$

Example 3 : Find the logarithm of 0.00278633.

Answer : The characteristic of this number is $\bar{3}$, as there are two zeros following the decimal point. We can find the mantissa of only

four significant figures. Hence, we neglect the last 2 figures (33) and find the mantissa of 2786 which is 4449.

$$\therefore \log 0.00278633 = \bar{3}.4449$$

When the last figure of a number consisting of more than 4 significant figures is equal to or more than 5, the figure next to the left of it is raised by one and so on till we have only four significant figures and if the last figure is less than 5, it is neglected as in the above example.

If we have the number 2786.58, the last figure is 8 therefore we shall raise the next in left figure to 6 and since 6 is greater than 5, we shall raise the next figure 6 to 7 and find the logarithm of 2787.

I 1.5.2 ANTILOGARITHMS

The number whose logarithm is x is called antilogarithm and is denoted by $\text{antilog } x$.

Thus, since $\log 2 = 0.3010$, then $\text{antilog } 0.3010 = 2$.

Example 1 : Find the number whose logarithm is 1.8088.

Answer : For this purpose, we use antilogarithms table which is used for fractional part.

- (i) In Example 1, fractional part is 0.8088. The first two figures from the left are 0.80, the third figure is 8 and the fourth figure is also 8.
- (ii) In the table of the antilogarithms, first look in the vertical column for 0.80. In this horizontal row under the column headed by 8, we find the number 6427 at the intersection. It means the number for mantissa 0.808 is 6427.
- (iii) In continuation of this horizontal row and under the mean difference column on the right under 8, we find the number 12 at the intersection. Adding 12 to 6427 we get 6439. Now 6439 is the figure of which .8088 is the mantissa.
- (iv) The characteristic is 1. This is one more than the number of digits in the integral part of the required number. Hence, the number of digits in the integral part of the required number = $1 + 1 = 2$. The required number is 64.39 i.e., $\text{antilog } 1.8088 = 64.39$.

Example 2 : Find the antilog of $\bar{2}.8088$.

Answer : As the characteristic is $\bar{2}$, there should be one zero on the

right of decimal in the number, hence $\text{antilog } \bar{2}.8088 = 0.06439$.

Properties of logarithms:

$$(i) \log_a mn = \log_a m + \log_a n$$

$$(ii) \log_a m/n = \log_a m - \log_a n$$

$$(iii) \log_a m^n = n \log_a m$$

The definition of logarithm:

$$\log_a 1 = 0 \text{ [since } a^0 = 1]$$

The log of 1 to any base is zero,

and $\log_a a = 1$ [since the logarithm of the base to itself is 1, $a^1 = a$]

I 1.6 NATURAL SINE / COSINE TABLE

To find the sine or cosine of some angles we need to refer to Tables of trigonometric functions. Natural sine and cosine tables are given in the DATA SECTION. Angles are given usually in degrees and minutes, for example : $35^\circ 6'$ or 35.1° .

I 1.6.1 READING OF NATURAL SINE TABLE

Suppose we wish to know the value of $\sin 35^\circ 10'$. You may proceed as follows:

- (i) Open the Table of natural sines.
- (ii) Look in the first column and locate 35° . Scan horizontally, move from value 0.5736 rightward and stop under the column where 6' is marked. You will stop at 0.5750.
- (iii) But it is required to find for $10'$.

The difference between $10'$ and $6'$ is $4'$. So we look into the column of mean difference under $4'$ and the corresponding value is 10. Add 10 to the last digits of 0.5750 and we get 0.5760.

Thus, $\sin (35^\circ 10')$ is 0.5760.

I 1.6.2 READING OF NATURAL COSINE TABLE

Natural cosine tables are read in the same manner. However, because of the fact that value of $\cos \theta$ decrease as θ increases, the mean difference is to be subtracted. For example, $\cos 25^\circ = 0.9063$. To read the value of cosine angle $25^\circ 40'$, i.e., $\cos 25^\circ 40'$, we read for $\cos 25^\circ 36' = 0.9018$. Mean difference for $4'$ is 5 which is to be subtracted from the last digits of 0.9018 to get 0.9013. Thus, $\cos 25^\circ 40' = 0.9013$.

I 1.6.3 R_{EADING OF NATURAL TANGENTS TABLE}

Natural Tangents table are read the same way as the natural sine table.

I 1.7 P_{LOTTING OF GRAPHS}

A graph pictorially represents the relation between two variable quantities. It also helps us to visualise experimental data at a glance and shows the relation between the two quantities. If two physical quantities a and b are such that a change made by us in a results in a change in b , then a is called independent variable and b is called dependent variable. For example, when you change the length of the pendulum, its time period changes. Here length is independent variable while time period is dependent variable.

A graph not only shows the relation between two variable quantities in pictorial form, it also enables verification of certain laws (such as Boyle's law) to find the mean value from a large number of observations, to extrapolate/interpolate the value of certain quantities beyond the limit of observation of the experiment, to calibrate or graduate a given instrument for measurement and to find the maximum and minimum values of the dependent variable.

Graphs are usually plotted on a graph paper sheet ruled in millimetre/centimetre squares. For plotting a graph, the following steps are observed:

- (i) Identify the independent variable and dependent variable. Represent the independent variable along the x-axis and the dependent variable along the y-axis.
- (ii) Determine the range of each of the variables and count the number of big squares available to represent each, along the respective axis.
- (iii) Choice of scale is critical for plotting of a graph. Ideally, the smallest division on the graph paper should be equal to the least count of measurement or the accuracy to which the particular parameter is known. Many times, for clarity of the graph, a suitable fraction of the least count is taken as equal to the smallest division on the graph paper.
- (iv) Choice of origin is another point which has to be done judiciously. Generally, taking (0,0) as the origin serves the purpose. But such a choice is to be adopted generally when the relation between variables begins from zero or it is desired

to find the zero position of one of the variables, if its actual determination is not possible. However, in all other cases the origin need not correspond to zero value of the variable. It is however convenient to represent a round number nearest to but less than the smallest value of the corresponding variable. On each axis mark only the values of the variable in round numbers.

- (v) The scale markings on x-and y-axis should not be crowded. Write the numbers at every fifth cm of the axis. Write also the units of the quantity plotted. Use scientific representations of the numbers i.e. write the number with decimal point following the first digit and multiply the number by appropriate power of ten. The scale conversion may also be written at the right or left corner at the top of the graph paper.
- (vi) Write a suitable caption below the plotted graph mentioning the names or symbols of the physical quantities involved. Also indicate the scales taken along both the axes on the graph paper.
- (vii) When the graph is expected to be a straight line, generally 6 to 7 readings are enough. Time should not be wasted in taking a very large number of observations. The observations must be covering all available range evenly.
- (viii) If the graph is a curve, first explore the range by covering the entire range of the independent variable in 6 to 7 steps. Then try to guess where there will be sharp changes in the curvature of the curve. Take more readings in those regions. For example, when there is either a maximum or minimum, more readings are needed to locate the exact point of extremum, as in the determination of angle of minimum deviation (δm) you may need to take more observations near about δm .
- (ix) Representation of "data" points also has a meaning. The size of the spread of plotted point must be in accordance with the accuracy of the data. Let us take an example in which the plotted point is represented as $\odot$, a point with a circle around it. The central dot is the value of measured data. The radius of circle of 'x' or 'y' side gives the size of uncertainty. If the circle radius is large, it will mean as if uncertainty in data is more. Further such a representation tells that accuracy along x- and y-axis are the same. Some other representations used which give the same meaning as above are $\square$, $\triangle$, $\blacksquare$, $\blacktriangle$, $\times$, etc.

In case, uncertainty along the x-axis and y-axis are different, some of the notations used are $\dagger$ (accuracy along x-axis is more than that on y-axis); $+$ (accuracy along x-axis is less

than that on y-axis). $\oplus$, $\odot$, $\bullet$, $\blacksquare$ are some of such other symbols. You can design many more on your own.

- (x) After all the data points are plotted, it is customary to fit a smooth curve judiciously by hand so that the maximum number of points lie on or near it and the rest are evenly distributed on either side of it. Now a days computers are also used for plotting graphs of a given data.

I 1.7.1 SLOPE OF A STRAIGHT LINE

The slope m of a straight line graph AB is defined as

$$m = \frac{\Delta y}{\Delta x}$$

where Δy is the change in the value of the quantity plotted on the y-axis, corresponding to the change Δx in the value of the quantity

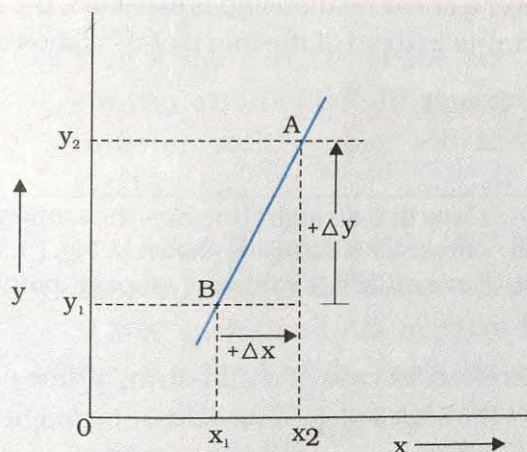


Fig. I 1.2 Value of slope is positive

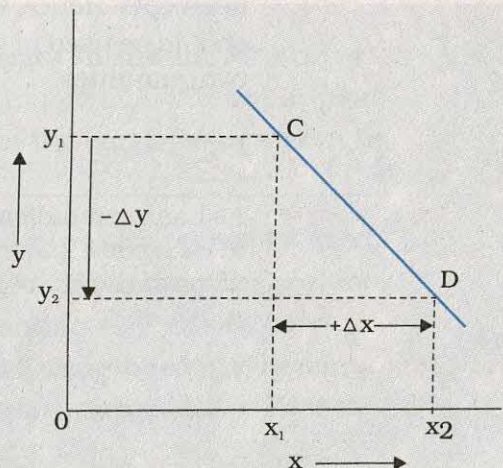


Fig. I 1.3 Value of slope is negative

plotted on the x-axis. It may be noted that the sign of m will be positive when both Δx and Δy are of the same sign, as shown in Fig. I 1.2. On the other hand, if Δy is of opposite sign (i.e., y decreases when x increases) than that of Δx , the value of the slope will be negative. This is indicated in Fig. I 1.3.

Further, the slope of a given straight line has the same value, for all points on the line. It is because the value of y changes by the same amount for a given change in the value of x , at every point of the straight line, as shown in Fig. I 1.4. Thus, for a given straight line, the slope is fixed.

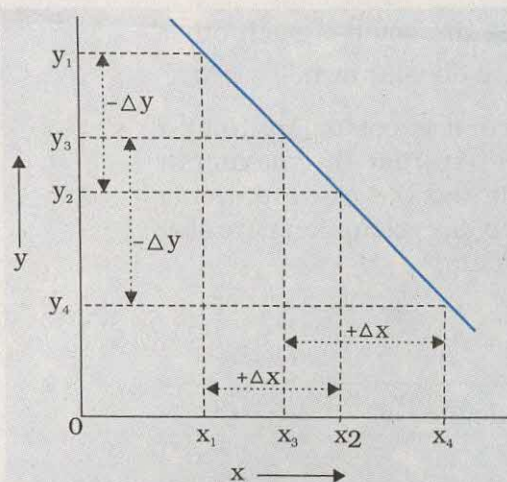


Fig. I 1.4 Slope is fixed for a given straight line

While calculating the slope, always choose the x-segment of sufficient length and see that it represents a round number of the variable. The corresponding interval of the variable on y-segment is then measured and the slope is calculated. Generally the slope should not have more than two significant digits. The values of the slope and the intercepts, if there are any, should be written on the graph paper.

Do not show slope as $\tan\theta$. Only when scales along both the axes are identical slope is equal to $\tan\theta$. Also keep in mind that slope of a graph has physical significance, not geometrical.

Often straight-line graphs expected to pass through the origin are found to give some intercepts. Hence, whenever a linear relationship is expected, the slope should be used in the formula instead of the mean of the ratios of the two quantities.

I 1.7.2 SLOPE OF A CURVE AT A GIVEN POINT ON THE CURVE

As has been indicated, the slope of a straight line has the same value at each point. However, it is not true for a curve. As shown in Fig. I 1.5, the slope of the curve CD may have different values of slope at points A', A, A'', etc.

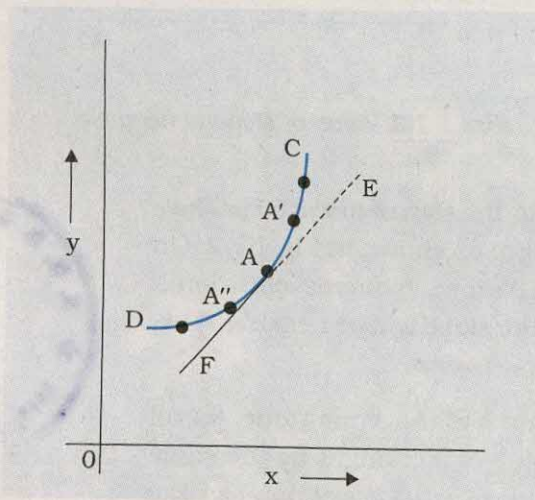


Fig. I 1.5 Tangent at point A

Therefore, in case of a non-straight line curve, we talk of the slope at a particular point. The slope of the curve at a particular point, say point A in Fig. I 1.5, is the value of the slope of the line EF which is the tangent to the curve at point A. As such, in order to find the slope of a curve at a given point, one must draw a tangent to the curve at the desired point.

In order to draw the tangent to a given curve at a given point, one may use a plane mirror strip attached to a wooden block, so that it stands perpendicular to the paper on which the curve is to be drawn. This is illustrated in Fig. I 1.6 (a) and Fig. I 1.6 (b). The plane mirror strip MM' is placed at the desired point A such that the image

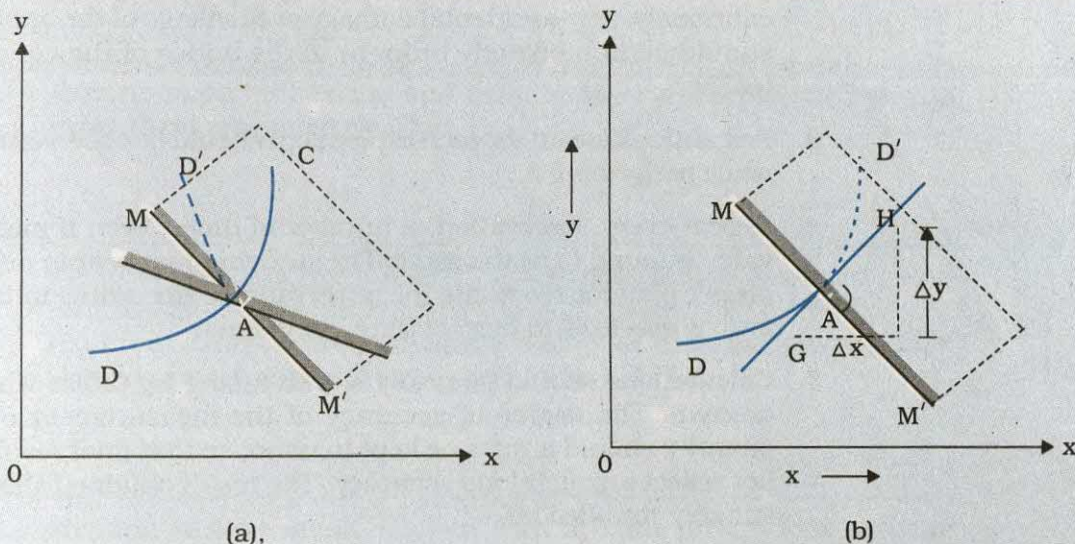


Fig. I 1.6 (a), (b) Drawing tangent at point A using a plane mirror

D'A of the part DA of the curve appears in the mirror strip as continuation of DA. In general, the image D'A will not appear to be smoothly joined with the part of the curve DA as shown in Fig. I 1.6 (a).

Next rotate the mirror strip MM', keeping its position at point A fixed. The image D'A in the mirror will also rotate. Now adjust the position of MM' such that DAD' appears as a continuous, smooth curve as shown in Fig. I 1.6 (b). Draw the line MAM' along the edge of the mirror for this setting. Next using a protractor, draw a perpendicular GH to the line MAM' at point A.

GAH is the line, which is the required tangent to the curve DAC at point A. The slope of the tangent GAH (i.e., $\Delta y / \Delta x$) is the slope of the curve CAD at point A. The above procedure may be followed for finding the slope of any curve at any given point.

I 1.8 GENERAL INSTRUCTIONS FOR PERFORMING EXPERIMENTS

1. The students should thoroughly understand the principle of the experiment. The objective of the experiment and procedure to be followed should be clear before actually performing the experiment.
2. The apparatus should be arranged in proper order. To avoid any damage, all apparatus should be handled carefully and

cautiously. Any accidental damage or breakage of the apparatus should be immediately brought to the notice of the concerned teacher.

3. Precautions meant for each experiment should be observed strictly while performing it.
4. Repeat every observation, a number of times, even if measured value is found to be the same. The student must bear in mind the proper plan for recording the observations. Recording in tabular form is essential in most of the experiments.
5. Calculations should be neatly shown (using log tables wherever desired). The degree of accuracy of the measurement of each quantity should always be kept in mind, so that final result does not reflect any fictitious accuracy. The result obtained should be suitably rounded off.
6. Wherever possible, the observations should be represented with the help of a graph.
7. Always mention the result in proper SI unit, if any, along with experimental error.

I 1.9 GENERAL INSTRUCTIONS FOR RECORDING EXPERIMENTS

A neat and systematic recording of the experiment in the practical file is very important for proper communication of the outcome of the experimental investigations. The following heads may usually be followed for preparing the report:

DATE:-----

EXPERIMENT NO:-----

PAGE NO.-----

AIM

State clearly and precisely the objective(s) of the experiment to be performed.

APPARATUS AND MATERIAL REQUIRED

Mention the apparatus and material used for performing the experiment.

DESCRIPTION OF APPARATUS INCLUDING MEASURING DEVICES (OPTIONAL)

Describe the apparatus and various measuring devices used in the experiment.

TERMS AND DEFINITIONS OR CONCEPTS (OPTIONAL)

Various important terms and definitions or concepts used in the experiment are stated clearly.

PRINCIPLE / THEORY

Mention the principle underlying the experiment. Also, write the formula used, explaining clearly the symbols involved (derivation not required). Draw a circuit diagram neatly for experiments/activities related to electricity and ray diagrams for light.

PROCEDURE (WITH IN-BUILT PRECAUTIONS)

Mention various steps followed with in-built precautions actually observed in setting the apparatus and taking measurements in a sequential manner.

OBSERVATIONS

Record the observations in tabular form as far as possible, neatly and without any overwriting. Mention clearly, on the top of the observation table, the least counts and the range of each measuring instrument used. If the result of the experiment depends upon certain conditions like temperature, pressure etc., then mention the values of these factors.

CALCULATIONS AND PLOTTING GRAPH

Substitute the observed values of various quantities in the formula and do the computations systematically and neatly with the help of logarithm tables. Calculate experimental error.

Wherever possible, use the graphical method for obtaining the result.

RESULT

State the conclusions drawn from the experimental observations. [Express the result of the physical quantity in proper significant figures of numerical value along with appropriate SI units and probable error]. Also mention the physical conditions like temperature, pressure etc., if the result happens to depend upon them.



4.7.2011

PRECAUTIONS

Mention the precautions actually observed during the course of the experiment/activity.

SOURCES OF ERROR

Mention the possible sources of error that are beyond the control of the individual while performing the experiment and are liable to affect the result.

DISCUSSION

The special reasons for the set up etc., of the experiment are to be mentioned under this heading. Also mention any special inferences which you can draw from your observations or special difficulties faced during the experimentation. These may also include points for making the experiment more accurate for observing precautions and, in general, for critically relating theory to the experiment for better understanding of the basic principle involved.

A_{IM}

To determine resistance per unit length of a given wire by plotting a graph of potential difference versus current.

A_{PPARATUS AND MATERIAL REQUIRED}

A wire of unknown resistance ($\sim 10\Omega$), battery eliminator or an accumulator (0 to 3V) or two dry cells (1.5 V each), voltmeter (0-5 V), milliammeter (0-500 mA), rheostat, plug key, connecting wires and a piece of sand paper.

P_{RINCIPLE}

Ohm's law states that the electric current flowing through a conductor is directly proportional to the potential difference across its ends, provided the physical state of the conductor remains unchanged.

If I be the current flowing through the conductor and V the potential difference across its ends, then according to Ohm's law

$$V \propto I$$

and hence

$$V = RI$$

where R is the constant of proportionality and is termed as the electrical resistance of the conductor. If V is expressed in volts and I in amperes, then R is expressed in ohms. The resistance R , depends upon the material and dimensions of the conductor. For a wire of uniform cross-section, the resistance depends on the length l and the area of cross-section A . It also depends on the temperature of the conductor. At a given temperature the resistance

$$R = \rho \frac{l}{A}$$

where ρ is the specific resistance or resistivity and is characteristic of the material of wire.

(E 1.1)

(E 1.2)

Combining Eqs. (E 1.1) and (E 1.2) we have

(E 1.3)

$$V = \left(\rho \frac{l}{A} \right) I$$

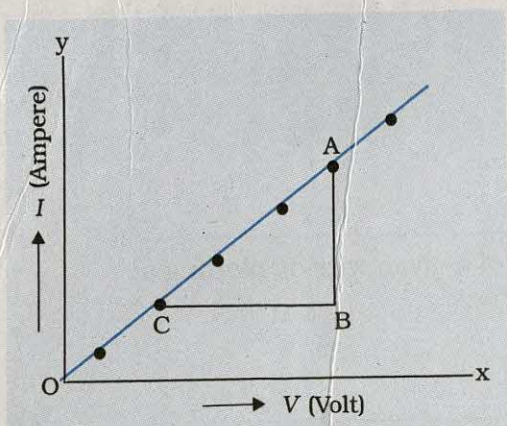


Fig. E 1.1 Graph between current I and potential difference, V

A linear relationship is obtained between V and I , i.e. the graph between V and I will be a straight line passing through the origin as shown in Fig. E 1.1. The slope of the graph is $1/R$ from Eq. (E 1.1) (Equation of straight line passing through origin is $y = mx$ where m is the slope of graph).

$$\text{Slope} = \frac{1}{R}$$

$$\Rightarrow R = \frac{1}{\text{slope}}$$

If l is the length of wire then the resistance per unit length of the wire $= \frac{R}{l}$.

PROCEDURE

1. Clean the ends of the connecting wires with the help of sand paper in order to remove any insulating coating on them.
2. Connect various components - resistance, rheostat, battery, key, voltmeter and ammeter as shown in Fig. E 1.2.

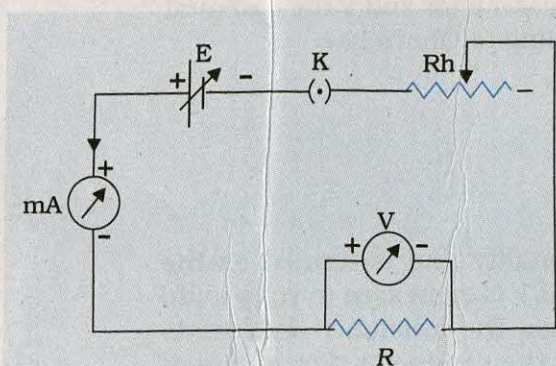


Fig. E 1.2 Circuit to find the relation between current I and potential difference, V for a given wire

3. Note whether pointers in milliammeter and voltmeter coincide with the zero mark on the measuring scale. If it is not so, adjust the pointer to coincide with the zero mark by adjusting the screw provided near the base of the needle using a screw driver.
4. Note the range and least count of the given voltmeter and milliammeter.
5. Insert the key K and slide the rheostat contact to one of its extreme ends, so that current passing through the resistance wire is minimum.
6. Note the milliammeter and voltmeter readings.

- Remove the key K and allow the wire to cool, if heated. Again insert the key. Shift the rheostat contact slightly to increase the applied voltage. Note the milliammeter and voltmeter reading.
- Repeat step 7 for four different settings of the rheostat. Record your observations in a tabular form.

OBSERVATIONS

- Range of ammeter = 0 ... mA to ...mA
- Least count of ammeter = ... mA
- Range of voltmeter = 0 ... V to ...V
- Least count of voltmeter = ...V
- Least count of metre scale = ... m
- Length of the given wire, $l = \dots\text{m}$

Table E 1.1: Voltmeter and milliammeter readings

Sl. No.	Applied potential difference [voltmeter reading V (V)]	Current flowing through the wire [milliammeter reading I (mA)]
	V	I
1		
2		
...		
6		

CALCULATIONS

- Plot a graph between the potential difference across the wire (V) and the current (I) flowing through it as shown in Fig. E 1.1.
- Determine the slope of the graph. The resistance of the given wire is then equal to the reciprocal of the slope.

From the graph $R = \frac{BC}{AB} = \dots \Omega$

- Resistance per unit length of given wire = $\frac{R}{l} = \dots \Omega \text{ m}^{-1}$

Error

$$\frac{\Delta R}{R} = \frac{\Delta V}{V} + \frac{\Delta I}{I} = \dots$$

(E 1.4)

Here, R is resistance per unit length and ΔR is estimated error. ΔV and ΔI are the least count of the voltmeter and milliammeter respectively.

R_{ESULT}

1. The potential difference across the given wire varies linearly with the current.
2. The resistance per unit length of the wire is $(R \pm \Delta R) = (... \pm ... \Omega m^{-1})$.

P_{RECAUTIONS}

1. The voltmeter should be connected in parallel and the ammeter in series with the circuit. It should be ensured that current enters at the positive terminal and leaves at the negative terminal.
2. The key should be inserted only while taking observations, as excessive flow of current causes unnecessary heating of the wire.
3. Zero error in measuring instruments (voltmeter, ammeter, metre scale) must be taken cognizance of and should be eliminated in case of ammeter and voltmeter by adjusting the pointer with the help of the screw provided at the base of the needle, using a screw driver.

S_{OURCES OF ERROR}

1. The wire used may not be of uniform area of cross-section.
2. The length of the resistance wire measured should be between one terminal of voltmeter and the other. The lengths of ends wound around the terminals of voltmeter, if included, would give error in measured length.

D_{ISCUSSION}

A resistor obeys Ohm's law. However, not all conducting devices obey Ohm's law e.g. diode, thyristor etc. These are called non-ohmic resistances.

S_{ELF ASSESSMENT}

1. A voltmeter is always connected in parallel and an ammeter in series with the circuit. Why? Will they record the respective parameters if connected in opposite manner?

- Why are copper wires normally used for connecting different components in an electric circuit?
- What happens if the current is allowed to flow through the circuit continuously for a long time? Why?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

- Study the effect of length of wire on its resistance when its diameter is kept constant.
- Study the effect of diameter of wire on its resistance when its length is kept constant by using different SWG (standard wire gauge) wires available in the market.
- Study the resistivity of wires made up of different materials. Is the resistivity of all wires same?
- Two uniform wires of the same material have the same length. One has circular cross section of area A while the other is not circular but has the same area of cross section A . Will their resistances be equal?
- Study the voltage current relationship for the filament of a torch bulb.
- Set up a circuit as shown in Fig. E 1.3.

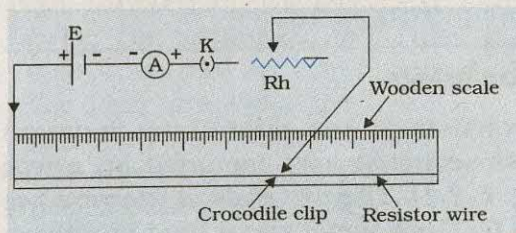


Fig. E 1.3

Note the ammeter reading I by connecting the crocodile clip at 10, 20, 30 cm length of wire. Plot a graph between $1/I$ and l . Find its slope and interpret its result. Can you use the graph to check the homogeneity of the resistance wire?

- Four resistances R_1 , R_2 , R_3 and R_4 are connected together as shown in Fig. E 1.4. Complete the electric circuit by connecting the combination of resistances to a 6 V source, an ammeter and a voltmeter. Explain, how would you measure current/voltage flowing through each one of the resistors.

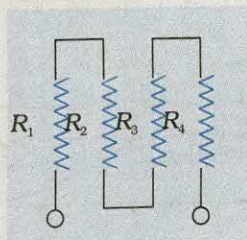


Fig. E 1.4

EXPERIMENT 2

AIM

To determine the resistance of a given wire using a metre bridge and hence determine the resistivity of the material of the wire.

APPARATUS AND MATERIAL REQUIRED

Metre bridge, a wire about 1m long (of material whose specific resistance is to be determined), a resistance box, a rheostat, galvanometer, a jockey, one-way key, a cell or battery eliminator, thick connecting wires, sand paper, screw gauge.

DESCRIPTION OF APPARATUS

Metre bridge

It consists of one metre long constantan wire AC of uniform cross-sectional area mounted on a wooden board with a scale (Fig. E 2.1). The two ends of the wire are attached to terminals A and C. Thick metal strips bent at right angles are used to provide two gaps E and F to connect resistors forming a Wheatstone's

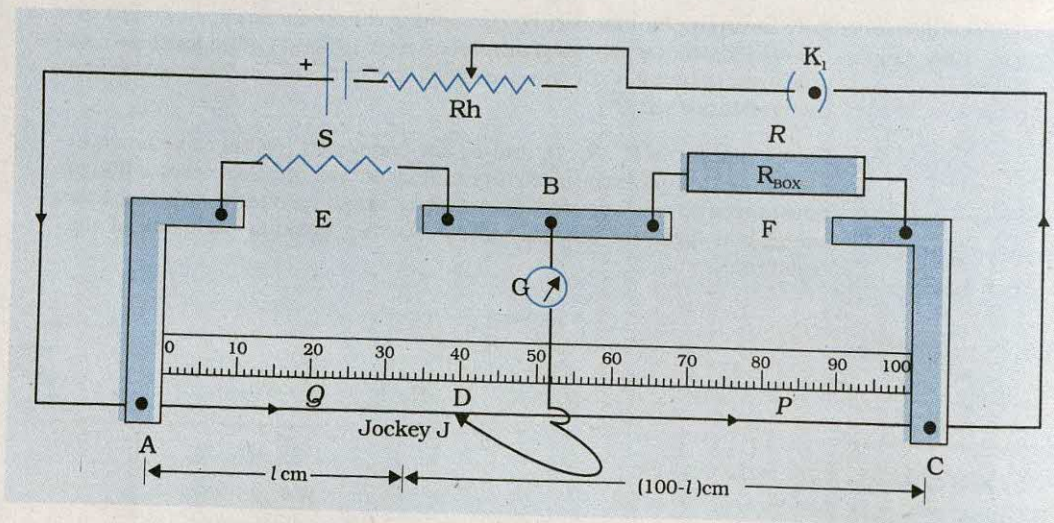


Fig. E 2.1 A metre bridge

bridge (Fig. E 2.2). The terminal B between the gaps is used for connecting galvanometer and other end of the galvanometer is connected to a jockey J.

PRINCIPLE

A metre bridge works on the principle of Wheatstone's bridge. As shown in Fig. E 2.2, it consists of four resistors P , Q , R and S connected in the form of a network ABCD. The terminals A and C are connected to two terminals of a cell through a key K_1 . Terminals B and D are connected to a sensitive galvanometer G through a key K_2 .

If there is no deflection in the galvanometer G , then balance condition for Wheatstone's bridge is

$$\frac{P}{Q} = \frac{R}{S}$$

(E 2.1)

We use this relation (E 2.1) to determine S if P , Q and R are known.

The unknown resistance S is connected in the gap E and a resistance box (R_{Box}) in gap F of the metre bridge. The terminal B is connected to one terminal of the galvanometer G . The other terminal of the galvanometer is connected to a jockey J which slides along the wire AC. A source of dc current is connected between A and C through a key K_1 so as to provide a constant potential drop along AC (Fig. E 2.1).

A resistor (or wire) of known resistance is inserted in the gap F by taking out corresponding key from the resistance box R_{Box} . The jockey is moved on the wire AC to obtain a condition of no-deflection in the galvanometer. It happens when the jockey is kept at a point D called the null point. In this condition;

$$\frac{P}{Q} = \frac{R}{S} = \frac{\text{Resistance of wire of length DC}}{\text{Resistance of wire of length AD}}$$

(E 2.2)

Unknown resistance S of the wire, having uniform cross-sectional area, is then given by

$$S = R \times \frac{l}{100 - l}$$

(E 2.3)

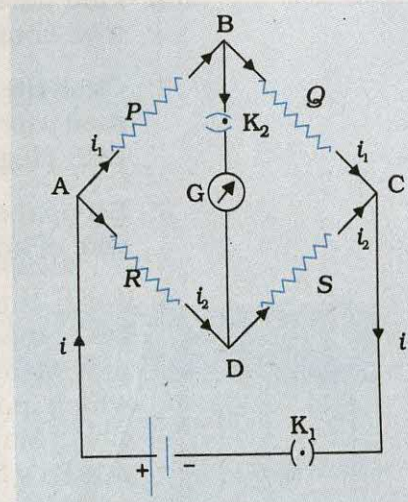


Fig.E 2.2 The Wheatstone's bridge

Because, for a wire of uniform cross-sectional area, resistance is proportional to length.

Thus, knowing l and R , and using Eq. (E 2.3), the unknown resistance S can be determined.

Resistivity

The specific resistance or resistivity ρ of the material of the given wire is

$$\rho = \frac{Sa}{L}$$

where S is the resistance of the wire of length L and $a = \pi r^2$, (r being the radius) is the area of cross-section.

P ROCEDURE

1. Find the average diameter of the wire with a screw gauge. From this, obtain the value of its radius r .
2. Clean the insulation at the ends of connecting wires with a piece of sand paper. Tighten all plugs of the resistance box (R_{BOX}) by pressing each plug.
3. Set up the circuit as shown in Fig. E 2.1 with unknown resistance wire of known length in gap E.
4. Next, introduce some resistance R in the circuit from the resistance box. Bring the jockey J in contact with terminal A first and then with terminal C. Note the direction in which pointer of the galvanometer gets deflected in each case. Make sure that jockey remains in contact with the wire for a fraction of a second. If the galvanometer shows deflection on both sides of its zero mark for these two points of contact of the jockey, null point will be somewhere on the wire AC. If it is not so, adjust resistance R so that the null point is somewhere in the middle of the wire AC, say, between 30 cm and 70 cm.
5. If there is one-sided deflection, check the circuit again, especially junctions, for their continuity.
6. Repeat step 4 for four different values of resistance R .
7. Interchange the position of the resistances S and R and repeat steps 4 to 6 for the same five values of R . While interchanging S and R , ensure that the same length of wire of resistance S is now in the gap F. The interchange takes care of unaccounted resistance offered by terminals.

OBSERVATIONS

1. Length of the wire of unknown resistance, $L = \dots \text{cm}$
2. Measurement of diameter of wire of unknown resistance

Least count of the screw gauge (L.C.) = $\dots \text{mm}$

Zero error of the screw gauge = $\dots \text{mm}$

Zero correction of the screw gauge = $\dots \text{mm}$

Table E 2.1: Diameter of Wire

Sl. No.	Reading along one direction			Reading along mutually perpendicular direction			Mean Diameter
	Main scale reading p (mm)	Coinciding circular scale division n	Diameter $d_1 = p + n \times \text{L.C.}$ (mm)	Main scale reading p' (mm)	Coinciding circular scale division n'	Diameter $d_2 = p' + n' \times \text{L.C.}$ (mm)	$d = \frac{d_1 + d_2}{2}$ (mm)
1							
2							
3							

Mean diameter (corrected for zero error) = $\dots \text{mm}$

Radius of wire $r = \dots \text{mm}$

Table E 2.2: Unknown resistance

Sl. No.	S in the left gap					S in the right gap										
	Resistance R Ω (ohm)	Position of balance point D (cm)	Balancing length AD (l) (cm)	Length DC = $100 - l$ (cm)	$S_1 = R \times \frac{l}{100 - l}$ Ω (ohm)	Position of balance point D' (cm)	Balancing length AD' = l' (cm)	Length D'C' = $100 - l'$ (cm)	$S_2 = R \times \frac{l'}{100 - l'}$ Ω (ohm)	Mean resistance $S = \frac{S_1 + S_2}{2}$ Ω (ohm)	ρ $\Omega \text{ m}$	ΔS_1 Ω	ΔS_2 Ω	ΔS Ω	$\Delta \rho$ $\Omega \text{ m}$	
1																
2																
...																
5																
Mean																

CALCULATIONS

$$L = \dots \text{ cm} \quad r = \dots \text{ mm} \quad S = \dots \Omega$$

Substituting these values in $\rho = S \frac{\pi r^2}{L}$, calculate the value of ρ in ohm-m.

Error

(E 2.4)

$$\frac{\Delta \rho}{\rho} = \frac{\Delta S}{S} + \frac{2\Delta r}{r} + \frac{\Delta L}{L}$$

Errors Δr , ΔL are the least counts of the measuring instruments and error ΔS is the maximum of the values obtained by following equations :

(E 2.5)

$$\Delta S_1 = \left[\frac{\Delta l}{l} + \frac{\Delta l}{(100 - l)} \right] S_1$$

(E 2.6)

$$\Delta S_2 = \left[\frac{\Delta l'}{l'} + \frac{\Delta l'}{(100 - l')} \right] S_2$$

If it is presumed that resistance offered by the resistance box is the same as that indicated on it, then $\Delta R = 0$

Therefore, maximum error is $\Delta S = \Delta S_1 + \Delta S_2$

RESULT

1. The unknown resistance of the given wire is found to be $S + \Delta S = \dots \pm \dots \Omega$
2. The resistivity of the material of the wire is $\rho \pm \Delta \rho = \dots \pm \dots \Omega \text{ m}$
Here S and ρ are mean values. ΔS and $\Delta \rho$ are maximum of the five values of error.

PRECAUTIONS

1. All the connections and plugs should be tight.
2. Jockey should be moved gently over the metre bridge wire.
3. The plug in the key (K_1) should be inserted only at the time of taking observations.
4. Null points should be in the middle of the wire (30 cm to 70 cm).

SOURCES OF ERROR

1. The metre bridge wire may not be of uniform area of cross-section.
2. Effect of end resistances due to copper strips, connecting screws, may affect the measurement.
3. The length L of the wire should not include the lengths below the terminals when placed in gap E or F.
4. The resistances of end pieces/metal strips may not be negligible. The error introduced by it can be reduced by interchanging the known and unknown resistances in gaps E and F.
5. The length measurements l and l' may have error if the metre bridge wire is not taut and along the scale in the metre bridge.
6. Galvanometer pointer is expected to be at zero when no current flows through it. However, many times it is observed that it is not so. In such cases, pointer has to be adjusted to zero by gently moving the screw below the scale with the help of a screw driver. Otherwise null point must be obtained by tapping the jockey on the wire.

DISCUSSION

1. It is generally preferred that R and S combination should be so chosen that the balance point comes near the middle of the metre bridge wire. Why? Is the sensitivity of detecting balance point best when R and S have same order of resistance?
2. The accuracy with which the null point can be detected also depends upon the sensitivity of the galvanometer used. To investigate this, find the distance through which the jockey has to be moved to cause a just perceptible deflection of the galvanometer. How can the error due to this be minimised? Does it have something to do with the potential difference between A and C?
3. The length l , that is, the position of the jockey, may be read upto, ± 0.1 cm (say). How much uncertainty will be introduced in the result due to this error?
4. It is advised that key should be unplugged when readings are not being taken to avoid unnecessary heating of the wire. Why? In what way, will the heating affect the null point? Will it be significant?

SELF ASSESSMENT

1. The bridge wire may not be exactly 100 cm long, so record its exact length and use this in the calculation.
2. If the metre bridge wire is not of uniform area of cross section, how will it affect the observations?

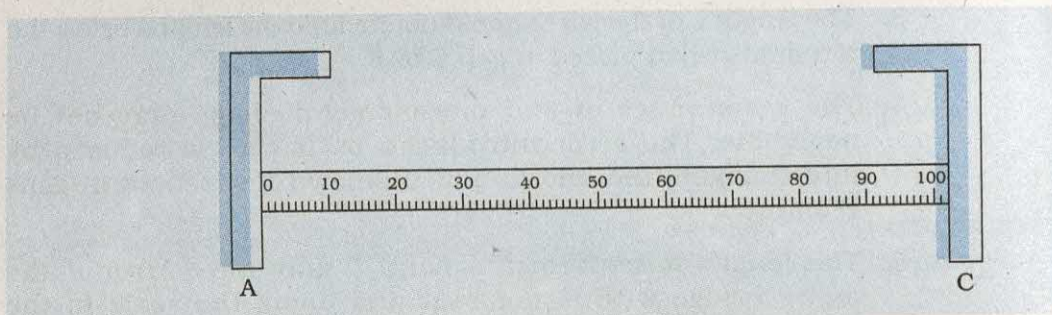


Fig. E 2.3 Defective scale of a metre bridge

3. If the metre bridge wire is not made of a material of uniform density, how will it affect the observations?
4. If the same experiment is performed with $AC = 50$ cm wire instead of 1 m, what changes would be there in the result?
5. The scale attached along the wire may not indicate the exact length as shown in Fig. E 2.3. How would you minimise the error?
6. Why is the metre bridge not suitable for measuring very high/very low resistances?
7. Why is the metre bridge preferred for determining the resistance of a wire over the Ohm's law circuit?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Determine the resistance of an electric bulb of given voltage and power. Attach crocodile clips at the end of two copper wires. Use these to connect the bulb in the gap E as shown in Fig. E 2.4. Why does the resistance obtained by you differ from the theoretical value?
2. Making use of your observations plot a graph between $(100 - l)/l$ and R . Find the slope of the graph. What does it represent?
3. The resistance of a wire changes with temperature. You may study this by using a metre bridge. You may use a beaker with mustard oil, a suitable thermometer ($0-300^\circ\text{C}$) and resistance wire of known length. The experimental set-up shown in Fig. E 2.5 may be used.

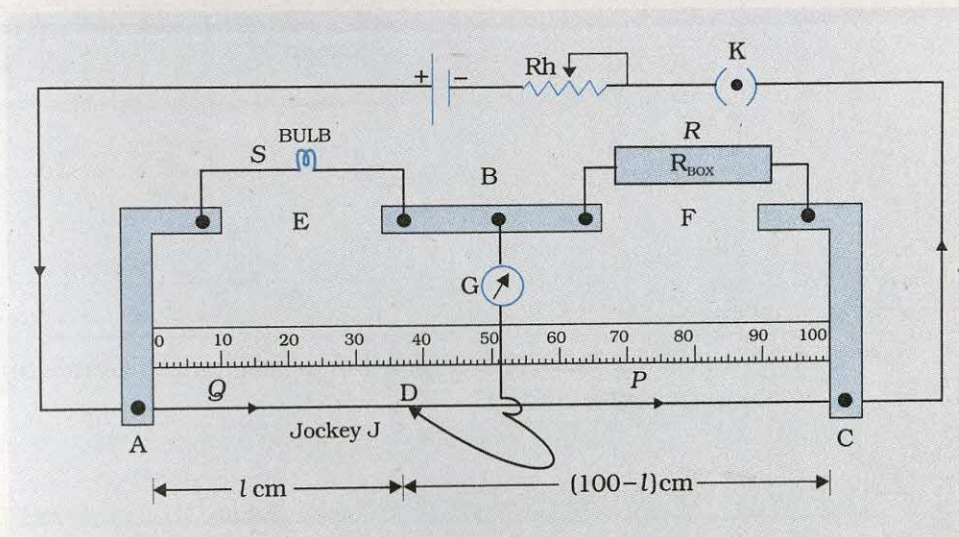


Fig. E 2.4

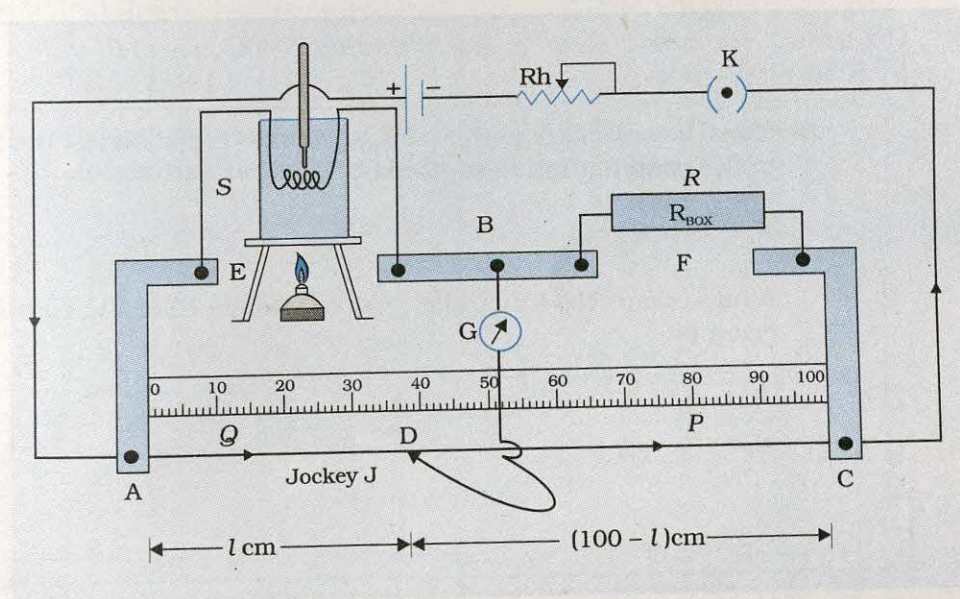


Fig. E 2.5

EXPERIMENT 3

AIM

To verify the laws of combination of resistances (series and parallel) using a metre bridge.

APPARATUS AND MATERIAL REQUIRED

A metre bridge, a sensitive galvanometer, two different resistances (carbon or wire-wound resistors), a resistance box, a jockey, a rheostat, a plug key, a cell or battery eliminator, thick connecting wires and a piece of sand paper.

PRINCIPLE

When two resistances R_1 and R_2 are connected in series, the resistance of the combination R_s is given by

(E 3.1)

$$R_s = R_1 + R_2$$

When connected in parallel, the resistance R_p of the combination is given by

(E 3.2)

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$$

PROCEDURE

1. Set up the circuit as shown in Fig. E 3.1.
2. Tighten all plugs in the resistance box (R_{BOX}) by rotating and pressing each plug to ensure that all plugs make good electrical contacts. Clean the ends of connecting wires using a sand paper before making the connections.
3. Remove some plug(s) from the resistance box to get suitable value of resistance R . Obtain the null point D on the metre bridge wire by sliding the jockey between ends A and C as was done in Experiment 2.

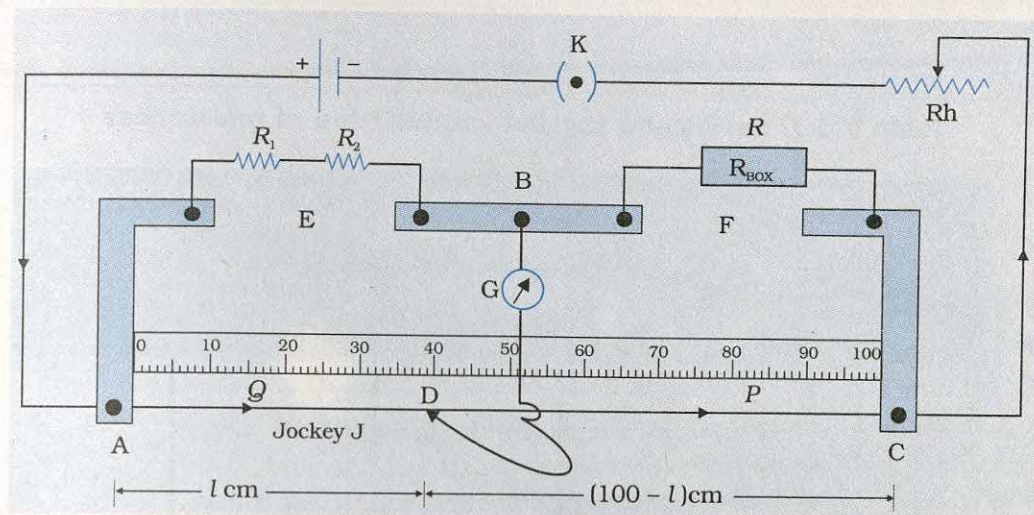


Fig. E 3.1 Resistances R_1 and R_2 connected in series to one arm of a metre bridge

4. Note resistance R and lengths AD and DC in the observation table.
5. Calculate the experimental value of the equivalent series resistance (X) of combination of resistances as shown in Table E 3.1.
6. Repeat the experiment for four more values of resistances R . Obtain the mean value of unknown resistance.

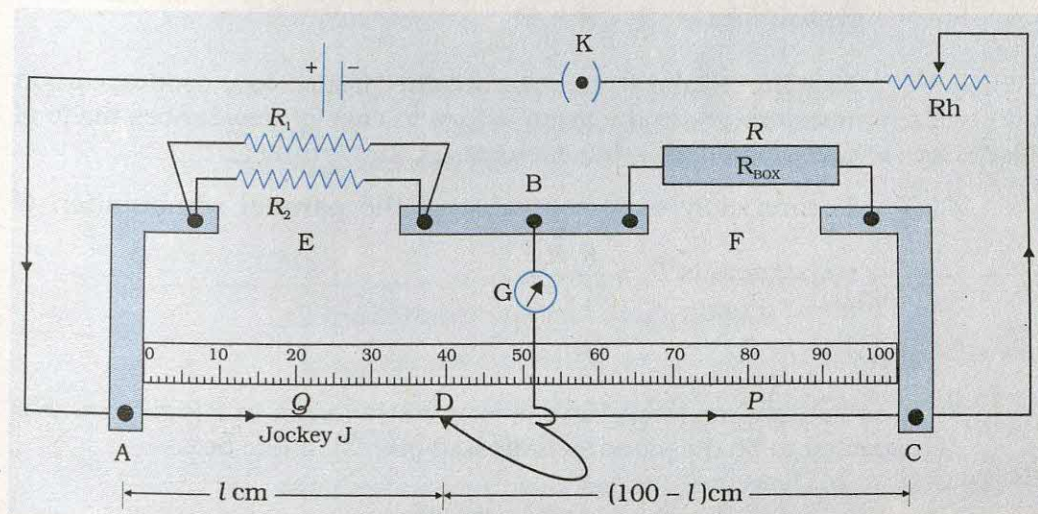


Fig. E 3.2 Resistances R_1 and R_2 connected in parallel to one arm of a metre bridge

7. Repeat steps 2 - 6 by connecting resistances R_1 and R_2 in parallel as shown in Fig. E 3.2 and calculate the experimental value of the equivalent parallel resistance (X) of combination of resistance.

OBSERVATIONS

Table E 3.1: Series and parallel combination of resistances

	Sl No.	Resistance R (ohm)	Length $AD = l$ (cm)	Length $DC, l' = 100 - l$ (cm)	Unknown resistance $X(R_s \text{ or } R_p) = \frac{R \times l}{l'}$ (ohm)	ΔR_s or ΔR_p (ohm)
R_1 and R_2 in series, R_s	1					
	2					
	--					
	5					
					Mean $R_s =$	
R_1 and R_2 in parallel, R_p	1					
	2					
	--					
	5					
					Mean $R_p =$	

CALCULATIONS

- The theoretically expected value of the series combination of resistances is $R_s = R_1 + R_2$

Note that R_1 and R_2 are to be obtained from colour code on carbon resistors or are the given values in case of resistances made of wires of materials like nichrome, constantan etc.

- Theoretically expected value of the parallel combination of resistances is $R_p = \frac{R_1 R_2}{R_1 + R_2}$

Error

In estimating errors, we have presumed that error in R is zero i.e., R is expected to be the same as indicated on resistance box.

(E 3.3)

In such a case,

$$\frac{\Delta R_s}{R_s} = \frac{\Delta l}{l} + \frac{\Delta l'}{l'}$$

where R_s , l and l' values are to be taken from the Observation Table E 3.1, Δl , $\Delta l'$ indicate the least count of the measuring scale on the metre bridge.

$$\text{i.e.} \quad \Delta R_s = R_s \left[\frac{\Delta l}{l} + \frac{\Delta l'}{l'} \right] \quad (\text{E 3.4})$$

$$\text{Similarly,} \quad \Delta R_p = R_p \left[\frac{\Delta l}{l} + \frac{\Delta l'}{l'} \right] \quad (\text{E 3.5})$$

Maximum of the five values of ΔR_s and ΔR_p should be reported as the estimation in errors. It can be seen from equation (E 3.4) and (E 3.5) that the error will be minimum if balancing lengths $l \approx l'$.

Therefore the null points should be obtained in the central region of the wire AC. For this reason, it is essential to plug out resistances from resistance box such that resistances in the left and right gaps are comparable.

RESULT

Table E 3.2: Theoretical and experimental values of resistance

	Theoretically expected resistance(Ω)	Experimentally obtained resistance (Ω)
Series Combination	$R_1 + R_2$	$R_s \pm \Delta R_s$
Parallel Combination	$\frac{R_1 R_2}{R_1 + R_2}$	$R_p \pm \Delta R_p$

R_s and R_p are the mean values of equivalent resistance for the combination of R_1 and R_2 in series and in parallel respectively.

PRECAUTIONS

1. All the connections and plugs should be tight.
2. Jockey should be moved gently over the metre bridge wire.
3. Plug keys of the resistance box should be made tight by rotating it in clockwise direction.
4. Null points should be in the central region of the wire (30 cm to 70 cm).

SOURCES OF ERROR

1. The jockey should not be pressed too hard on the metre bridge wire. Otherwise, the wire may become non-uniform during the course of time.

2. The length measurement l and l may have error if the metre bridge wire is not taut and along the scale in the metre bridge.
3. If large current is passed for a sufficiently long time, the wire AC may get heated and its resistance may change considerably during the time of experiment.
4. Galvanometer pointer is expected to be at zero when no current flows through it. However, many a time it is observed that it is not so. In such cases, pointer has to be adjusted to zero by gently moving the screw below the scale with the help of a screw driver. Otherwise, null point must be obtained by sliding the jockey on wire AC and observing the point, where tapping the galvanometer does not produce any deflection in it.
5. Many a time, it is found that the resistance offered by resistance box is not the same as is indicated on it. Therefore, the error in R will cause an additional error in the result.

DISCUSSION

1. It may be noted that if carbon resistors are used, ΔR_1 and ΔR_2 are to be obtained from tolerance limits shown by band of the colour codes* marked on them and error ΔR_s and ΔR_p can also be calculated using these values as shown in *Example 2.10 (p.27) in PHYSICS Textbook for Class XI Part-I (NCERT, 2006)*. Maximum of values of ΔR_s and ΔR_p so obtained together with that from equations (E 3.4) and (E 3.5) should be reported as estimation in errors.
2. The accuracy with which the null point can be detected also depends upon the sensitivity of the galvanometer. To investigate sensitivity, find the distance through which the jockey has to be moved to cause a just perceptible deflection of the galvanometer. Make a note of the range of distance over which null point is obtained at all points. Ideally, this range should not be more than the least count of the measuring scale.
3. In some cases, it is possible that the bridge wire is not exactly 100 cm long. In such cases its exact length should be used for the calculation.
4. If resistances R_1 and R_2 are made of wires of materials like constantan, nichrome etc., their values along with the corrected errors in their measurement should be considered for calculating equivalent resistance.

SELF ASSESSMENT

1. Comment on the difference between theoretically expected and experimentally obtained values of the effective resistances.

- Given n resistors of resistance R each, how will you combine them to get the maximum and the minimum effective resistance? Extend this experiment using filament of bulbs as resistors.
- Identify some method(s) to reduce the effect of 'end-resistance' at connections between the wire and copper strip or because of the improper soldering of wire.
- How will the sensitivity of metre bridge change under following condition?

Rheostat head is moved from minimum resistance to maximum resistance positions.

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

- Replace the galvanometer with a torch bulb and repeat the experiment. Explain the variation in the glow of the bulb with position of jockey on wire AC (Fig. E.3.1).

- Making use of your observations, plot a graph between $\left(\frac{l'}{l}\right)$ and R taking

$\left(\frac{l'}{l}\right)$ on y-axis and R on x-axis. Find the unknown resistance from the slope of the graph.

- Use a wire of arbitrary length L . Measure its resistance across ends A and B, say R_1 , using the metre bridge. Next, fold the wire so as to reduce its length to $(L/2)$ and measure the new resistance, say R_2 , across the ends A' and B'. Finally, fold it again and repeat the observation for resistance across ends A' and B''. Plot a graph of n (number of folds) and the effective resistance, by folding the wire a number of times and obtaining resistances as described above. Take care that folded wires do not make electrical contact with each other at any point except at their ends (A, B, A', B' and A'', B'').

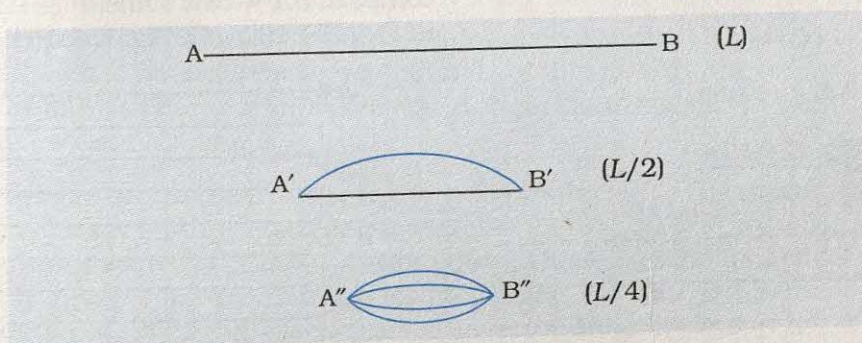


Fig. E 3.3

EXPERIMENT 4

Aim

To compare the emf of two given primary cells (Daniel and Leclanche cells) using a potentiometer.

APPARATUS AND MATERIAL REQUIRED

Potentiometer, a Leclanche cell, a Daniel cell, a two way key, a resistance box plug type (0 to 1000 Ω), a galvanometer (weston type), a voltmeter (0-3 V), a battery eliminator/lead accumulator, a low resistance rheostat (about 20 Ω), two one-way keys, connecting wires and sand paper.

DESCRIPTION OF APPARATUS

Potentiometer

A potentiometer consists of a uniform wire AB of low temperature coefficient of resistance stretched over a uniform wooden scale Fig. E 4.1(a). A B is often 100 cm, but for better accuracy it is also made of wire of length 400 cm or 1000 cm. Potentiometer wire is usually fixed on a wooden board with a 100 cm scale fixed alongside. To keep the arrangement compact, the wire is sometimes folded as shown in Fig. E 4.1(b) and Fig. E 4.1(c).

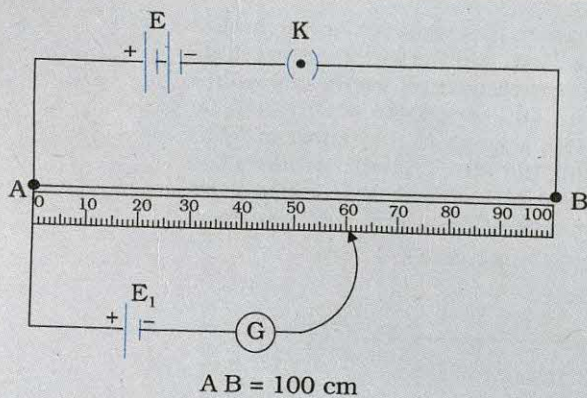


Fig. E 4.1 (a)

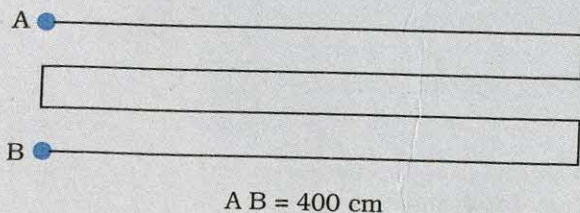


Fig. E 4.1 (b)

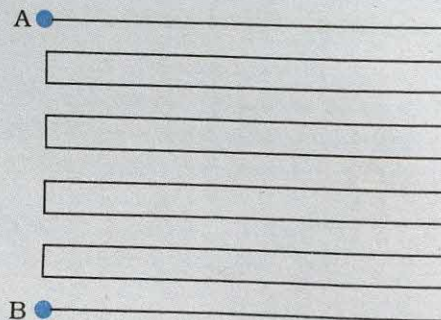


Fig. E 4.1 (c)

PRINCIPLE

With the help of a voltmeter we can measure only the potential difference between the two terminals of a cell, but using a potentiometer we can determine the value of emf of a given cell. The two primary cells whose emfs are to be compared, are so connected in the circuit that their positive terminals are joined together to the end A of the potentiometer wire AB and their negative terminals are joined to a galvanometer through a two-way key a, b, c. The other terminal of the galvanometer is connected to a jockey J. A resistance box, R_{BOX} , shunted with a key across its terminals, is also connected in the circuit between the two way key and the galvanometer G as shown in Fig. E 4.2.

The two primary cells with emfs E_1 and E_2 are connected in turn to the sliding contact J through the galvanometer G with the help of the two way key a, b, c.

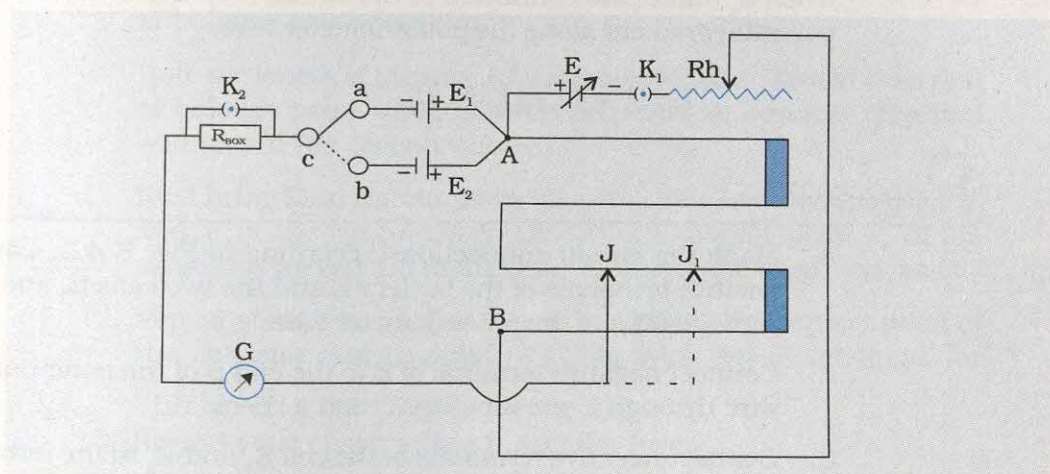


Fig. E 4.2 Circuit to compare emf of two primary cells

A steady potential difference could be maintained by using the battery E and rheostat Rh in series across the ends of the wire AB; the end A being at higher potential than the end B. Note that the emf $E > \text{emf } E_1$ and also $\text{emf } E > \text{emf } E_2$.

Close the gap 'a c' in the two way key to bring the cell E_1 in the circuit. Slide the jockey on the potentiometer wire to obtain null deflection in the galvanometer. Let it be at J. Note down the length AJ as l_1 cm. Similarly, bring E_2 into circuit by closing the gap 'b c' and obtain the null point J_1 by sliding the jockey along the wire. Note the length AJ₁ as l_2 cm.

Now, according to the principle of potentiometer, when a steady current flows through a wire of uniform thickness and material, potential

difference between any two points on it is directly proportional to the length of the wire between the points. Thus,

(E 4.1)

$$V \propto l$$

(E 4.2)

$$V = \phi l$$

where ϕ is potential gradient.

The length of potentiometer wire is increased to decrease ϕ . A lower value of ϕ makes the potentiometer more sensitive and accurate. In case of two cells we have

$$E_1 = \phi l_1$$

$$E_2 = \phi l_2$$

where E_1 and E_2 are emfs of two cells, l_1 and l_2 are the balancing lengths when E_1 and E_2 are connected to the circuit respectively and ϕ is the potential gradient along the potentiometer wire.

$$E_1/E_2 = \phi l_1/\phi l_2 = l_1/l_2$$

PROCEDURE

1. Make the circuit connections according to Fig. E 4.2. Connect positive terminals of the battery E and the two cells E_1 and E_2 to zero at end A of the potentiometer wire.
2. Connect negative terminal of E to the end B of the potentiometer wire through a one way key K_1 and a rheostat.
3. Connect negative terminals of the cell E_1 and E_2 to the terminals 'a' and 'b' of the two way key.
4. Shunt a resistance box R_{BOX} through a key K_2 . Connect common terminal of the two way key to one end of R_{BOX} .
5. Connect other end of the resistance box to a galvanometer whose other end is joined to a jockey. Jockey can be slid on the potentiometer wire to obtain null deflection in the galvanometer.
6. Bring the cell E_1 in the circuit by inserting the plug between the gaps 'a' and 'c' of the two way key.
7. Leave the key K_2 open. Make rheostat resistance minimum. Take out high resistance (of the order of thousand ohm) from the resistance box. Make contact of the jockey at the zero end of the potentiometer wire. Note the direction of deflection in the galvanometer.

8. Next, move the jockey to bring it in contact with the other end of the wire. Note whether the direction of deflection of the galvanometer needle is opposite to that observed in step 7.
9. If the deflection of galvanometer needle is in opposite direction in the above two situations, connections are correct. If not, look out for the reason. Connections might be loose or emf of the battery E might be less than that of the cells E_1 and E_2 . Make necessary changes as required.
10. Slide the jockey gently over the potentiometer wire till you get null deflection in the galvanometer. Plug in the key K_2 to get the accurate position of the null (or balance) point. The resistance in the resistance box limits the current flowing through the galvanometer. Near the balance point, the current flowing through the galvanometer is small, insertion of the key K_2 short circuits the resistances and hence increases the current. This improves the sensitivity of balance point detection.

Note the length of the wire AJ , and record it as l_1 . Repeat detection of balance point while moving the jockey in opposite direction and record the second value of l_1 .

11. Next bring E_2 in the circuit by inserting plug between the gaps 'b' and 'c' of the two way key. Obtain the balance point J_1 in the same way as you did in finding l_1 and note the length AJ_1 as l_2 .
12. Repeat steps 6 to 11 three times by shifting the contact point of the rheostat and calculate l_1/l_2 for each set of readings, for E_1 and E_2 .
13. Record your observations in tabular form.

OBSERVATIONS

1. No. of wires on the potentiometer board = ...
2. Range of the voltmeter = 0...V to ... V
3. Least count of the voltmeter = ...V
4. Potential drop across E = ...V
5. Potential drop across E_1 = ...V
6. Potential drop across E_2 = ...V

Table E 4.1: Balance length

Sl. No.	l_1 cm			l_2 cm			Ratio	$\Delta \left(\frac{E_1}{E_2} \right)$
	Leclanche cell (E_1) in the circuit			Daniel cell (E_2) in the circuit			$\frac{E_1}{E_2} = \frac{l_1}{l_2}$	
	Jockey being moved in one direction (i)	Jockey being moved in another direction (ii)	Mean	Jockey being moved in one direction (i)	Jockey being moved in another direction (ii)	Mean		
1								
2								
3								
4								
Mean								

CALCULATIONS

Calculate l_1 / l_2 for each set of readings.

Error

(E 4.3)

$$\frac{\Delta \left(\frac{E_1}{E_2} \right)}{\left(\frac{E_1}{E_2} \right)} = \frac{\Delta l_1}{l_1} + \frac{\Delta l_2}{l_2}$$

(E 4.4)

$$\therefore \Delta \left(\frac{E_1}{E_2} \right) = \left(\frac{\Delta l_1}{l_2} + \frac{\Delta l_2}{l_2} \right) \left(\frac{E_1}{E_2} \right)$$

Δl_1 and Δl_2 represent the error in the measurement of l_1 and l_2 respectively.

Calculate $\Delta \left(\frac{E_1}{E_2} \right)$ for the four sets of observations and write the maximum of the four values in the result as estimated error.

RESULT

The ratio of emfs E_1/E_2 for Leclanche cell to Daniell cell

$$= \frac{E_1}{E_2} \pm \Delta \left(\frac{E_1}{E_2} \right)_{\max.} = \dots \pm \dots$$

$\frac{E_1}{E_2}$ is mean value of the ratio of emfs of the two cells.

PRECAUTIONS

1. Keys plugged into the resistance box must ensure good electrical contact.
2. Jockey should be pressed gently on the potentiometer wire to prevent formation of any kinks in it.
3. Position of rheostat contact should not be disturbed before finishing the task of finding the balance length with both the cells.

SOURCES OF ERROR

1. The area of cross section of the potentiometer wire may not be uniform throughout its length.
2. Avoid continuous discharge of the two cells whose emf are to be compared by keeping the keys open when E_1 and E_2 are not in use.
3. The length measurement may have error if the potentiometer wire is not taut and along the scale on the board.
4. Multiple key jockey may not have correct alignment with the scale.

DISCUSSION

1. Current should not be passed for a long time in order to avoid heating due to current.
2. Battery E should have greater emf than that of E_1 and E_2 , the two primary cells, so that a balance point is obtained on the wire.
3. High resistance box is used in order to make currents low so that the galvanometer coil is not damaged.
4. When looking for a balance point, there may be a small range of positions (rather than one position) of the jockey for

which there is no visible deflection of galvanometer. A good estimate of the balance point in such a case is the middle point of that range.

SELF ASSESSMENT

1. A voltmeter connected across the terminals of a battery measures the potential difference. How is it different from emf?
2. What would you conclude if galvanometer needle keeps shaking in your experimental set up?
3. Use a voltmeter to obtain the ratio of potential difference of the two cells. Does it differ considerably from the ratio of their emfs? If not, what can you conclude?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Can the resistances of two resistors be compared using a potentiometer? If yes, draw a circuit diagram and perform the experiment.
2. Plot a graph of l_1 and l_2 with l_1 on y-axis and l_2 on x-axis. Calculate $\frac{E_1}{E_2}$ from the slope of graph.
3. Compare emf of cells available in the market and draw bar graphs for dry cells of different makes.

EXPERIMENT 5

AIM

To determine the internal resistance of a given primary cell using a potentiometer.

APPARATUS AND MATERIAL REQUIRED

Potentiometer, Leclanche cell or dry cell, an ammeter, one resistance box ($R_{\text{BOX 1}}$) (about 0-50 Ω), 3 one way plug keys, galvanometer, a high resistance box ($R_{\text{BOX 2}}$) (about 0-10 k Ω), a low resistance rheostat of about 20 Ω , jockey, lead accumulator and connecting wires.

PRINCIPLE

When a resistance R is connected across a cell of emf E and internal resistance r , then the current I in the circuit is

$$I = \frac{E}{R + r} \quad \text{(E 5.1)}$$

The potential difference $V (= RI)$ across the two terminals of the cell is

$$V = \frac{E}{R + r} R \quad \text{(E 5.2)}$$

Thus
$$\frac{E}{V} = 1 + \frac{r}{R}$$

or
$$r = \left(\frac{E}{V} - 1 \right) R \quad \text{(E 5.3)}$$

If l_0 and l are the distances of the balance null point from end A of the potentiometer for an open and a closed circuit respectively (Fig. E 5.1), then E is proportional to l_0 and V is proportional to l .

$$\frac{E}{V} = \frac{l_0}{l} \quad \text{(E 5.4)}$$

From Eqs. (E 5.3) and (E 5.4)

(E 5.5)

$$r = \left(\frac{l_0 - l}{l} \right) R$$

PROCEDURE

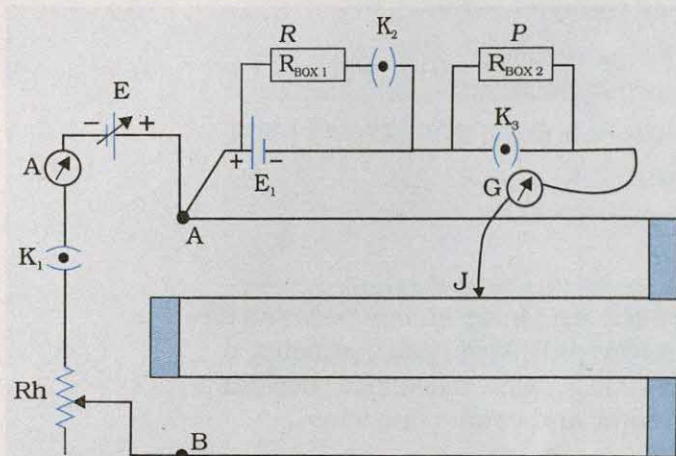


Fig. E 5.1 Circuit to measure internal resistance of a primary cell using a potentiometer

1. Connect different electrical components as shown in the circuit (Fig. E 5.1). After checking the circuit connections, close key K_1 .
2. With keys K_2 and K_3 open and a protective high resistance P from the $R_{\text{BOX } 2}$, find the position of the balance point. For final reading, short circuit the resistance P by closing the key K_3 and find the balance length l_0 .
3. Take $R = 10 \, \Omega$ (from $R_{\text{BOX } 1}$), close the key K_2 and quickly measure the new balance length l . Open K_2 as soon as this has been done.
4. Keep the readings in the ammeter constant throughout the above observation.

5. Reduce the value of R in equal steps of $1 \, \Omega$ and for each value of R obtain the balance length l .
6. At the end of the experiment, open key K_2 and repeat step 2 to find l_0 again.

OBSERVATIONS

$l_0 = \dots \text{ cm}$ (in the beginning of the experiment)

$l_0 = \dots \text{ cm}$ (at the end of the experiment)

Mean $l_0 = \dots \text{ cm}$.

Table E 5.1: Balance length

Sl. No.	$R \, \Omega$	$l \, \text{cm}$	$\frac{1}{R} \, \Omega^{-1}$	$\frac{1}{l} \, \text{cm}^{-1}$	$r = \left(\frac{l_0 - l}{l} \right) R \, \Omega$
1					
2					
...					
6					

CALCULATIONS

1. Substitute the value of l_0 , l and corresponding value of R in

Eq. (E 5.5) and calculate the value of r , where $r = \left(\frac{l_0 - l}{l} \right) R$.

2. Use graphical method also to obtain r . Note that Eq (E 5.5) can be written as

$$\frac{1}{R} = \frac{l_0}{r} \left(\frac{1}{l} \right) - \frac{1}{r} \quad \text{(E 5.6)}$$

It is an equation of a straight line (Fig. E 5.2).

3. Plot a graph between $1/R$ and $1/l$, taking

$\frac{1}{l}$ on the x-axis and $\frac{1}{R}$ on y-axis.

4. Draw a straight line as close to the points plotted as you can. The negative intercept on the y-axis gives the value of $1/r$. Hence, obtain the value of r (Fig. E 5.2).

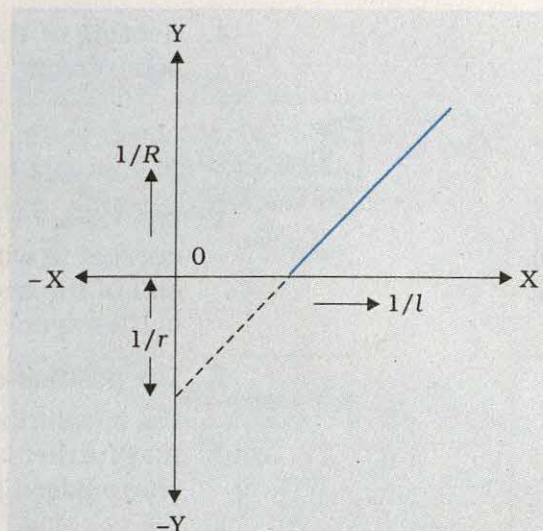


Fig. E 5.2 Graph between $1/R$ and $1/l$

RESULT

The internal resistance of the given cell r

- (i) by calculation ... Ω
- (ii) by graph ... Ω

PRECAUTIONS

1. The primary cell whose internal resistance is to be determined should not be disturbed during the experiment or else its internal resistance may change.
2. The emf of battery E should be more than the emf of the primary cell, E_1 .
3. Positive terminals of E and E_1 both should be connected at the same point on the potentiometer.
4. Always measure length from point A i.e. the point at which positive terminals of battery are connected and measure this length upto the balance point.

5. Insert K_1 and K_2 only when readings are taken otherwise the wires may get heated up due to continuous flow of current and may also affect the internal resistance of the cell.

SOURCES OF ERROR

1. Potentiometer wire may not be of uniform cross - section.
2. Brass strips at the ends may have a finite resistance.
3. Emf of the auxiliary battery producing the drop of potential along the wire may not be constant throughout the course of the experiment.
4. Heating of the potentiometer wire by current may introduce some error.

DISCUSSION

1. The theory of potentiometer assumes that there is a steady current in wire AB during the period of experiment. Therefore, emf of the accumulator should be constant during the course of the experiment.
2. The position of the jockey can be read within the least count of the measuring scale $\pm 0.1\text{cm}$. Moreover, the edge of the jockey may further limit this least count. It is therefore advised to use a sharp edged jockey.
3. There may also be a zero error in the measurement of l , due to the end of the scale not being exactly at the end of the wire.

SELF ASSESSMENT

1. All the positive terminals of sources of emf are joined at point A of potentiometer, but if all the negative terminals of sources of emf are joined at point A then how will the balance length be affected?
2. Find the internal resistance of a freshly prepared Leclanche cell. Does its internal resistance change with R ?
3. State the factors on which the internal resistance of a cell depends.

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Find the internal resistance of dry cells of different makes.
2. Can the internal resistance of a secondary cell be determined by this method? Give reason for your answer.

EXPERIMENT 6

AIM

To determine the resistance of a galvanometer by half-deflection method and to find its figure of merit.

APPARATUS AND MATERIAL REQUIRED

A moving coil galvanometer, a battery or a battery eliminator (0 - 6 V), one resistance box ($R_{\text{BOX } 1}$) of range 0 - 10 k Ω , one resistance box ($R_{\text{BOX } 2}$) of range 0 - 200 Ω , two one way keys, voltmeter, connecting wires and a piece of sand paper.

PRINCIPLE

Galvanometer

Galvanometer is a sensitive device used to detect very low current. Its working is based on the principle that a coil placed in a uniform magnetic field experiences a torque when an electric current is set up in it. The deflection of the coil is determined by a pointer attached to it, moving on the scale.

When a coil carrying current I is placed in a radial magnetic field, the coil experiences a deflection θ which is related to I as

$$I = k\theta$$

where k is a constant of proportionality and is termed as figure of merit of the galvanometer.

The circuit arrangement required for finding the resistance G of the galvanometer by half deflection method is shown in Fig. E 6.1.

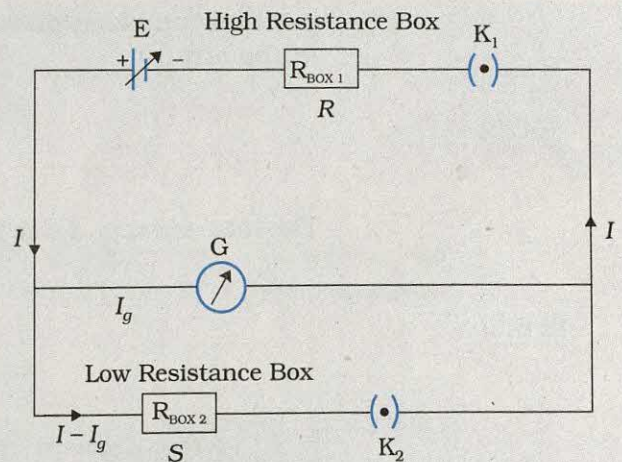


Fig. E 6.1 Circuit for finding resistance of galvanometer

(E 6.1)

When a resistance R is introduced in the circuit, the current I_g flowing through it is given by

(E 6.2)

$$I_g = \frac{E}{R + G}$$

In this case, the key K_2 is kept open. Here E is the emf of battery, G is the resistance of the galvanometer whose resistance is to be determined.

If the current I_g produces a deflection θ in the galvanometer, then from equation (E 6.1) we get

(E 6.3)

$$I_g = k\theta$$

Combining equations (E 6.2) and (E 6.3) we get

(E 6.4)

$$\frac{E}{R + G} = k\theta$$

On keeping both the keys K_1 and K_2 closed and by adjusting the value of shunt resistance S , the deflection of the galvanometer needle becomes $\frac{1}{2}$ (half). As G and S are in parallel combination and R in series with it, the total resistance of the circuit

(E 6.5)

$$R' = R + \frac{GS}{G + S}$$

The total current, I due to the emf E in the circuit is given by

(E 6.6)

$$I = \frac{E}{R + \frac{GS}{G + S}}$$

If I'_g is the current through the galvanometer of resistance G , then

$$G I'_g = S (I - I'_g)$$

(E 6.7)

or,

$$I'_g = \frac{IS}{G + S}$$

Substituting the value of I from Equation (E 6.6), in equation (E 6.7) the current I'_g is given by

$$\left[I'_g = \frac{IS}{G+S} = \frac{E}{R + \frac{GS}{G+S}} \cdot \frac{S}{G+S} \right]$$

$$I'_g = \frac{ES}{R(G+S) + GS}$$

(E 6.8)

For galvanometer current I'_g , if the deflection through the galvanometer is reduced to half of its initial value $\left(= \frac{\theta}{2} \right)$ then

$$I'_g = k \left(\frac{\theta}{2} \right) = \frac{ES}{R(G+S) + GS}$$

On dividing Eq. (E 6.2) by Eq. (E 6.8),

$$\frac{I_g}{I'_g} = \frac{E}{R+G} \times \frac{R(G+S) + GS}{ES} = 2$$

$$\text{or, } R(G+S) + GS = 2S(R+G)$$

$$\Rightarrow RG = RS + GS$$

$$\Rightarrow G(R-S) = RS$$

$$\text{or, } G = \frac{RS}{R-S}$$

(E 6.9)

By knowing the values of R and S , the galvanometer resistance G can be determined. Normally R is chosen very high ($\sim 10 \text{ k}\Omega$) in comparison to S ($\sim 100 \Omega$) for which

$$G \approx S$$

The figure of merit (k) of the galvanometer is defined as the current required for deflecting the pointer by one division. That is

$$k = \frac{I}{\theta}$$

(E 6.10)

For determining the figure of merit of the galvanometer the key K_2 is opened in the circuit arrangement.

Using Eqs. (E 6.2) and (E 6.3) the figure of merit of the galvanometer is given by

$$k = \frac{1}{\theta} \left(\frac{E}{R+G} \right)$$

(E 6.11)

By knowing the values of E , R , G and θ the figure of merit of the galvanometer can be calculated.

PROCEDURE

1. Clean the connecting wires with sand paper and make neat and tight connections as per the circuit diagram (Fig. E 6.1).
2. From the high resistance box ($R_{\text{BOX 1}}$) (1-10 k Ω), remove 5 k Ω key and then close the key K_1 . Adjust the resistance R from this resistance box to get full scale deflection on the galvanometer dial. Record the values of resistance, R and deflection θ .
3. Insert the key K_2 and keep R fixed. Adjust the value of shunt resistance S to get the deflection in the galvanometer which is exactly half of θ . Note down S . Remove plug K_2 after noting down the value of shunt resistance, S .
4. Take five sets of observations by repeating steps 2 and 3 so that θ is even number of divisions and record the observations for R , S , θ and $\frac{\theta}{2}$ in tabular form.
5. Calculate the galvanometer resistance G and figure of merit k of galvanometer using Eqs. (E 6.9) and (E 6.11) respectively.

OBSERVATIONS

Emf of the battery $E = \dots$ V

Number of divisions on full scale of galvanometer = ...

Table E 6.1: Resistance of galvanometer

Sl. No.	High Resistance	Deflection in the galvanometer	Shunt resistance	Half deflection in the galvanometer	$G = \frac{R \cdot S}{R - S}$	$k = \frac{E}{R + G} \cdot \frac{1}{\theta}$
	R (Ω)	θ (divisions)	S (Ω)	$\frac{\theta}{2}$ (divisions)	(Ω)	A/divisions
1						
2						
3						
4						
5						

CALCULATIONS

Mean value of G (resistance of galvanometer) = ... Ω

Mean value of k (figure of merit of galvanometer) = ... ampere/division.

RESULT

1. Resistance of galvanometer by half deflection method, $G = \dots \Omega$
2. Figure of merit of galvanometer, $k = \dots \text{ampere/division}$

PRECAUTIONS

1. Key K_1 should be inserted only after high value of R has been taken out from resistance box otherwise galvanometer coil may burn.
2. Adjust R such that deflection in galvanometer is of even division so that $\theta/2$ is more conveniently obtained.
3. Emf of the battery should be constant.
4. Use as high values of R as practically possible. This ensures correct value of G .
5. All the connections and plugs in the resistance box should be tight.

SOURCES OF ERRORS

1. Plugs in the resistance boxes may be loose or they may not be clean.
2. The emf of the battery may not be constant.

DISCUSSION

1. By closing the key K_2 and adjusting the value of resistance in resistance box $R_{\text{BOX } 2}$, you get the deflection $\theta/2$ in the galvanometer. Then the resistance S equals G , the resistance of galvanometer, because half of the current passing through R is shared by S and half by galvanometer. It is noteworthy that R is so large compared to S or G that opening or closing the key K_2 makes insignificant difference in the current passing through R .
2. We define current sensitivity C of the galvanometer as the deflection produced per unit current. With K_2 open, the current passing through it is

$$C\theta = \frac{E}{R}$$

$$C = \frac{E}{R\theta}$$

3. From eq. E 6.9, $RS = G(R - S)$. Galvanometer resistance G can also be determined from the slope of a graph plotted RS against $(R - S)$ with RS on y-axis and $(R - S)$ on x-axis.

SELF ASSESSMENT

- How will you use a galvanometer for measuring current?
- Out of galvanometer, ammeter and voltmeter which has the highest resistance and which has the lowest? Explain.
 - Which of the two meters has lower resistance – a milliammeter or a microammeter?
- What are the factors on which sensitivity of a galvanometer depends?
- Internal resistance of the cell is taken to be zero. This implies that we have to use a freshly charged accumulator in the experiment or use a good battery eliminator. If the internal resistance is finite, how will it affect the result?
- Is it possible to find the galvanometer resistance by taking $1/3$ deflection? If so what changes would be required in the formula for calculation of value of G .

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

- Plot a graph between R and $\frac{1}{\theta}$ (R along x-axis). Use the graph to determine G and k .
- Plot a graph of θ against $\left(\frac{E}{R+G}\right)$ with θ on y-axis and $\left(\frac{E}{R+G}\right)$ on x-axis.
How will you determine k from the graph?
- Use the values of G and k to calculate the value of shunt resistance required to convert the given galvanometer into an ammeter of 0 - 3 A range.
- Calculate the value of series resistance required to convert the given galvanometer into a voltmeter of 0 - 30 V range.

EXPERIMENT 7

AIM

To convert the given galvanometer (of known resistance and figure of merit) into (i) an ammeter of a desired range (say 0 to 30 mA) and (ii) a voltmeter of desired range (say 0 to 3 V) and to verify the same.

APPARATUS AND MATERIAL REQUIRED

A galvanometer of known resistance and figure of merit, a constantan or manganin wire of 26 or 30 SWG, a battery or a battery eliminator, one way key, a rheostat of range $200\ \Omega$, an ammeter of 0-30 mA range, a voltmeter of 3 V range, connecting wires and sand paper.

(i) P

PRINCIPLE (CONVERSION OF GALVANOMETER INTO AN AMMETER)

A galvanometer is a sensitive device which can detect the presence of very small current in a circuit of the order of 100 μ A. For measuring current of the order of an ampere, a low resistance called shunt resistance S is connected in parallel across the galvanometer having resistance G .

If I_0 is the total current in the circuit for full scale deflection, then the current $(I_0 - I_g)$ passes through S , where I_g is current that flows through the galvanometer for full scale deflection. The instrument is calibrated so as to read the current directly in ampere and then it can be used as an ammeter. Since G and S are parallel to each other therefore, the potential difference across both are same, hence,

$$I_g G = (I_0 - I_g) S \quad \text{(E 7.1)}$$

$$\text{or} \quad S = \frac{I_g G}{I_0 - I_g} \quad \text{(E 7.2)}$$

The figure of merit of the galvanometer is represented by the symbol k which represents the current corresponding to one scale division; thus if N is the total number of divisions (on either side) of the galvanometer scale, the value of current I_g is given by

$$I_g = kN$$

if n represents the actual deflection in the converted galvanometer, then the total current will be

$$I = n \frac{I_o}{N}.$$

PROCEDURE

1. Determine the galvanometer resistance G and figure of merit k as per the procedure given in experiment 6.
2. Count the total number of divisions N on either side of zero of the galvanometer scale.
3. Calculate the current I_g for full scale deflection in the galvanometer by using the relation $I_g = Nk$, where k is the figure of merit of the galvanometer.

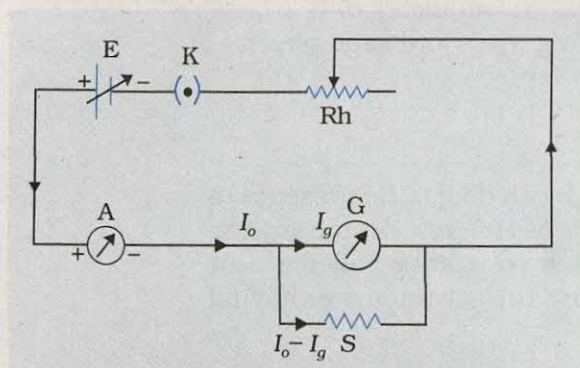


Fig. E 7.1 Circuit to verify conversion of galvanometer into an ammeter

4. Calculate the shunt resistance S using the formula $S = \frac{I_g G}{I_o - I_g}$.
5. Measure the radius r of the wire and from the given value of the specific resistance ρ , calculate the length of the wire l , for resistance S [use the formula $l = \frac{S\pi r^2}{\rho}$].
6. Let the calculated length of the wire be 10 cm. Then cut 3-4 cm extra and put it in parallel to the galvanometer and complete the circuit as shown in Fig. E 7.1.
7. Adjust the length of the wire so that when we see full scale deflection in the galvanometer, the current in the ammeter is 30 mA.
8. Thus the galvanometer is now converted to an ammeter whose range is 30 mA.
9. Now measure the exact length of the shunt wire and calculate its resistance by using the previously measured value of radius and the known value of specific resistance.
10. Compare the above value of resistance to the one calculated using

$$\text{the formula } S = \frac{l \times \rho}{\pi r^2}.$$

OBSERVATIONS

1. Galvanometer resistance, G (given) = ... Ω
2. Figure of merit of the galvanometer, k (given) = ... ampere/division
3. Number of divisions on either side of zero of the galvanometer scale, N = ... division
4. Current required for producing full scale deflection of N divisions, $I_g = kN$ = ... ampere

5. Radius of wire:

Least count of the given screw gauge = ... cm

Zero error = ... cm

Zero correction = ... cm

Observed diameter of the wire:

- | | |
|--------------|-------------|
| (i) ... cm | (ii) ... cm |
| (iii) ... cm | (iv) ... cm |

Mean observed diameter, D = ... cm

Radius of the wire $r = D/2$ = ... cm

CALCULATIONS

1. Shunt resistance = $S = \frac{I_g G}{I_0 - I_g} = \dots \Omega$
2. Given value of specific resistance of the material of the wire $\rho = \dots \Omega \text{ m}$
3. Required length of wire, $l = \frac{S\pi r^2}{\rho} = \dots \text{ cm}$
4. Observed length of the shunt wire for the desired range, $l' = \dots \text{ cm}$
5. Shunt resistance from the observed length of the wire, $S' = \frac{l' \times \rho}{\pi r^2} = \dots \Omega$

RESULT

To convert the given galvanometer into an ammeter of the range, 0 to ... ampere

1. the calculated resistance of the shunt wire, $S = \dots \Omega$
2. the observed resistance of the shunt wire, $S' = \dots \Omega$

P RECAUTIONS

1. Use the ammeter for verification which has the same range as the range of conversion.
2. Cut about 3 to 4 cm extra to the calculated length of the wire.
3. After adjusting the length of the wire, measure the length of the wire between the two plugs carefully.

(ii) P RINCIPLE (CONVERSION OF GALVANOMETER INTO A VOLTMETER)

By connecting a high resistance of suitable value in series with a galvanometer, it is converted into a voltmeter. Voltmeter is always connected in parallel with the electrical component across which potential difference is to be measured.

If a galvanometer (having resistance G) shows a full scale deflection for a maximum current I_g , the potential difference across the galvanometer is $I_g G$. If the converted galvanometer is desired to have a range V_o volt, then the resistance to be joined in series with

galvanometer, is given by $R = \frac{V_o}{I_g} - G$.

P ROCEDURE

1. Calculate the value of the series resistance R for given values of V_o , I_g and G .
2. Make the connections as shown in Fig. E 7.2 by connecting a cell and converted galvanometer and the voltmeter of nearly the same range in parallel, with a high resistance rheostat R_h .
3. Close the key K and adjust the rheostat so that the voltage shown in the voltmeter is equal to the desired range (say 3 V). Simultaneously, adjust the position of the slider of the rheostat and also the resistance from the resistance box so that when full scale deflection is observed on the galvanometer, the voltmeter shows 3 V. Note the total resistance from the resistance box.

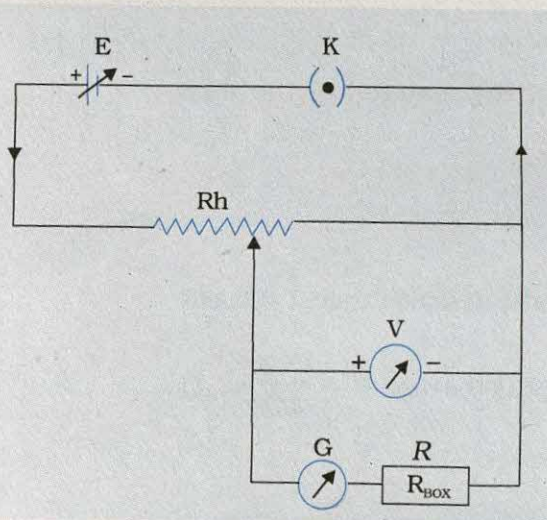


Fig. E 7.2 Circuit to verify conversion of galvanometer into a voltmeter

OBSERVATIONS

1. Resistance of the galvanometer, G (given) = ... Ω
2. The figure of merit of the galvanometer, k (given) = ... ampere/division
3. Number of divisions on either side of zero of the galvanometer scale, N = ... division
4. Current required for producing full scale deflection of N divisions, $I_g = k N$ = ... ampere
5. Total resistance taken out from the resistance box = ... Ω

CALCULATIONS

Resistance to be connected in series with the galvanometer,

$$R = \frac{V_0}{I_g} - G = \dots \Omega$$

RESULT

To convert the given galvanometer into a voltmeter of the range,
0 to ... V

1. The value of the calculated series resistance, R = ... Ω
2. The value of the observed series resistance, R' = ... Ω
3. Current for full scale deflection, I_g = ... ampere

PRECAUTIONS

1. The resistance box used should be of high resistance.
2. The rheostat should be used as potential divider.
3. High resistance of the order of 10 k Ω from the resistance box should be used first and then the battery key should be closed to avoid any damage to the galvanometer.

SOURCES OF ERROR

The wire may be of non-uniform area of cross section.

DISCUSSION

1. If the area of cross section of the wire is non-uniform, how will it affect the observation?
2. Use a rheostat as current divider and potential divider.
3. To check if friction in your instrument is small enough, measure θ in the same setting 5 to 10 times. If each time, the needle comes to exactly the same point on the scale, friction in your instrument is quite small.

SELF ASSESSMENT

1. How can you increase the range of the converted galvanometer to 0-60 mA?
2. How can you decrease the range of the converted galvanometer to 0-20 mA?
3. If $S \ll G$, what is the order of resistance of converted galvanometer?
4. Why is an ammeter always connected in series with the circuit?
5. Why is a voltmeter always connected in parallel with the circuit?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Calculate the length of the wire of same material if the radius is doubled.
2. Calculate the length of the wire if the radius is same but material used is copper.
3. Change the range of ammeter and voltmeter and repeat the same procedure as followed in the above experiment.
4. Use the converted ammeter/voltmeter for verification which has the same range as the range of conversion.

EXPERIMENT 8

AIM

To determine the frequency of alternating current using a sonometer and an electromagnet.

APPARATUS AND MATERIAL REQUIRED

A sonometer with a soft iron wire stretched over it, an electromagnet, a step-down transformer, slotted 1/2 kg weights hanger, a physical balance, two sharp edge wedges and a weight box.

PRINCIPLE

The frequency n of the fundamental mode of vibration of a stretched string, fixed at two ends, is given by

$$n = \frac{1}{2l} \sqrt{\frac{T}{m}}$$

(E 8.1)

Here l is the length of the vibrating string, T is the tension in the wire and m is its mass per unit length.

If an alternating current is passed in the coil of the electromagnet, the magnetisation produced in the core is proportional to instantaneous value of the current. If the electromagnet is held close to the middle of the sonometer wire, the wire will be attracted twice during each cycle towards the electromagnet. The attractive force experienced by the wire will be proportional to the magnetisation produced in the core of the electromagnet. Since in each cycle, the wire will be pulled twice and hence at resonance, it will vibrate with a frequency which is twice the frequency of alternating current. Hence, if f is the frequency of the alternating current, then

$$f = \frac{n}{2} = \frac{1}{4l} \sqrt{\frac{T}{m}}$$

(E 8.2)

$$4n^2 l^2 m = T$$

$$\text{or } l^2 = \frac{1}{4n^2 m} \times T$$

A graph between T (taken on x-axis), and l^2 (taken on y-axis), would be a straight line. The slope of this straight line would be

$$\frac{1}{4n^2 m}, \text{ so that}$$

(E 8.3)

$$n^2 = \frac{1}{4m \times \text{slope}}$$

$$n = \frac{1}{2} \sqrt{\frac{1}{m \times \text{slope}}}$$

The frequency of alternating current, $f = \frac{n}{2} = \frac{1}{4} \sqrt{\frac{1}{m \times \text{slope}}}$ can be determined using the value of the slope.

PROCEDURE

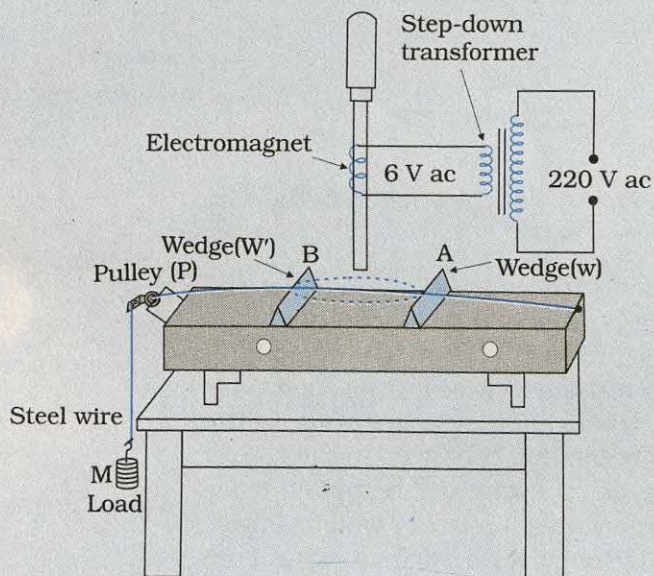


Fig. E 8.1 Set up for finding frequency of ac mains using a sonometer

1. Set up the sonometer and stretch the wire AB by placing a load of $\frac{1}{2}$ kg on the hanger (Fig. E 8.1).
2. Support the electromagnet in a stand and connect it to the secondary of a stepdown transformer. Adjust its position, such that its one pole lies close to the middle of the sonometer wire.
3. Switch on the alternating current supply and adjust the length of vibrating portion of AB by sliding the wedge W or W'. Make this adjustment until the amplitude of the vibrating string is maximum.
4. Measure the vibrating length and note the tension in the string.
5. Increase the load in steps of $\frac{1}{2}$ kg and each time find the vibrating length.
6. Switch off the ac supply. Untie the wire of the sonometer from its peg and find its mass in a physical balance. Calculate mass of 100 cm sonometer wire. Hence find the mass per unit length, m for the wire.

OBSERVATIONS

1. Length of the wire = ...cm = ... m
2. Mass of the wire = ...g = ...kg
3. Mass per unit length, $m = \dots$ g/cm = ...kg/m
4. Acceleration due to gravity, $g = \dots$ ms⁻²

Table E 8.1: Resonant length

Sl. No.	Load (M) including mass of hanger (kg)	Tension $T = mg$ (N)	Resonant length l			Mean l in (m)	$n = \frac{1}{2l} \sqrt{\frac{T}{m}}$ (Hz)
			First trial (cm)	Second trial (cm)	Mean (cm)		
1							
2							
3							
4							
Mean							

CALCULATIONS

1. For each set, calculate the value of n using the formula given above. Find the mean of these values.
2. Plot a graph of l^2 against T with l^2 on y-axis and T on x-axis. Determine the slope of the graph. Using the value of the slope determine the frequency of alternating current.

RESULT

1. The graph between T and l^2 is a straight line.
2. Slope of the graph = $\frac{1}{4mn^2} = \dots$
3. Frequency of ac supply $f = \frac{n}{2}$
 - (i) from calculation ...Hz
 - (ii) from graph ...Hz

PRECAUTIONS

1. Pulley should be as frictionless as possible.
2. Edges of the wedge should be sharp.
3. Tip of the electromagnetic pole should be close to the middle of the sonometer wire.
4. After taking each of the observations, circuit should be switched off for a few minutes.

SOURCES OF ERROR

1. Friction of the pulley is the main source of error in the experiment. Due to this, the value of tension acting on the wire is less than that actually applied.
2. AC frequency may not be stable.

DISCUSSION

1. The frequency of alternating current is half that of the frequency of the vibrating string.
2. Sonometer wire is made of soft iron for better results.

SELF ASSESSMENT

1. How is ac different from dc?
2. What is the meaning of frequency of ac?
3. How does the wire vibrate? Identify and explain the rule with the help of which you can determine the direction of force acting on the wire.
4. What should be the property of the iron for making it a good electromagnet?
5. Is there any relation between frequency and magnetism of the electromagnet, and frequency of the alternating current?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

Perform the above experiment using a permanent horse shoe magnet and passing the alternating current in the sonometer wire. In this case the resonant frequency is equal to the frequency of the alternating current. Sonometer wire need not be made of soft iron. You can use constantan or manganin wire for this purpose.

EXPERIMENT 9

AIM

To find the value of ' v ' for different values of ' u ' in case of concave mirror and to find the focal length.

APPARATUS AND MATERIAL REQUIRED

An optical bench, two sharp-edged needles (pins), concave mirror of less than 20 cm focal length, three uprights (with clamps), index needle (may be a knitting needle), metre scale and spirit level.

TERMS AND DEFINITIONS

1. *Principal axis* of a mirror is the line passing through the centre of curvature and pole of the mirror.
2. *Principal focus* is the point where rays parallel to principal axis, focus after reflection from the surface of the mirror (Fig. E 9.1).
3. *Geometrical centre* of the mirror is called pole, P.
4. *Focal length* is the distance between the pole, P and the focus, F.

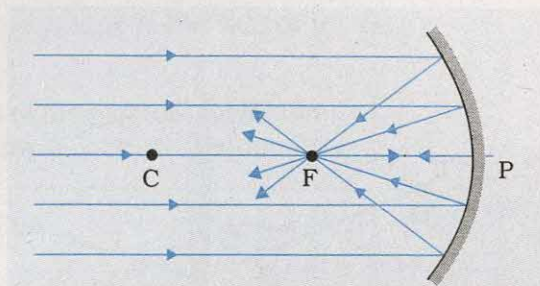
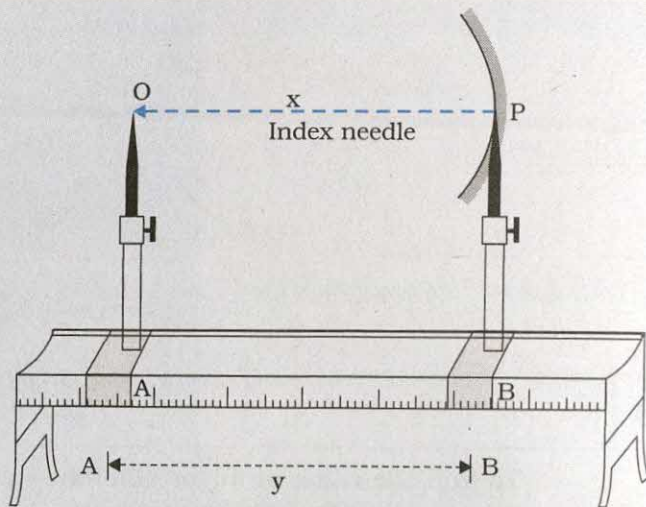


Fig. E 9.1 Focal length of a concave mirror.

INDEX CORRECTION

Usually the distance between concerned points of two elements is not the same as the distance between their uprights as read on the scale. For example, in Fig. E 9.2 the reading of two uprights do not give the actual distance between the tip of the pin and the pole of the mirror. A correction must, therefore, be applied. It is called the index correction.

Fig. E 9.2 Determination of Index correction



PARALLAX

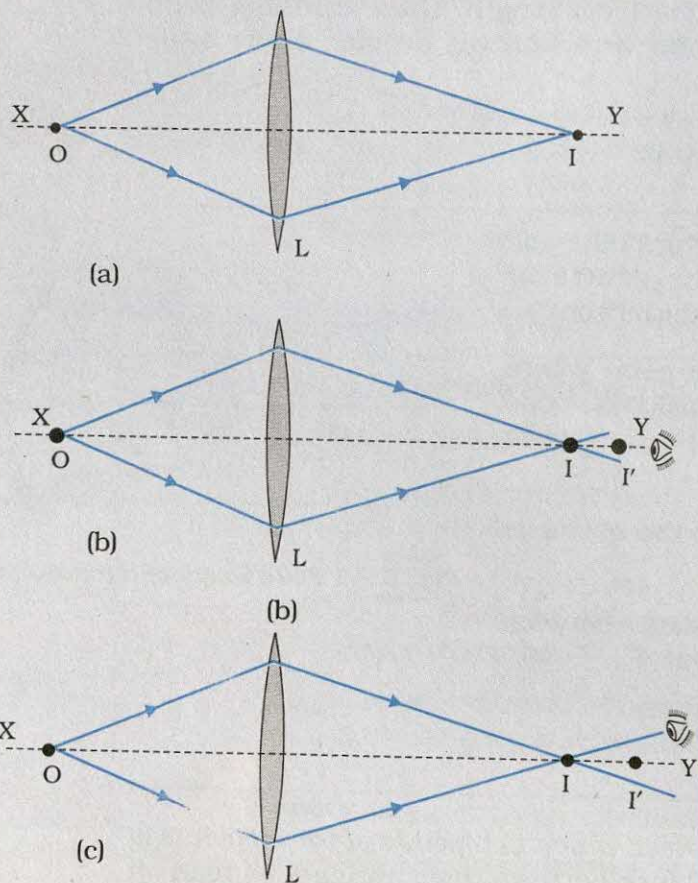


Fig. E 9.3 (a),(b),(c) Locating the position of an image on the optical bench by a pin

This is employed in the location of image of an object.

For example, as shown in the Fig. E 9.3 (a) O and I are the object and image points for a mirror/lens.

An object point O and its real image 'I' are conjugate points i.e. any of the two may be considered as object and the other as its image. Thus it helps in accurate adjustment to check for no parallax at both the points.

If we say there is no parallax between an object O (pin) and its image I, then by moving the eye through which we are observing, to the left and then to the right, object and its image both appear to move together relative to the lens/mirror. It implies that the position of both are same on the optical bench [Figs. E 9.3 (d) and (e)]. If their positions are not same then in one position they may appear to coincide and in another they will appear separate [Figs. E 9.3 (b) and (c)].

This method of locating the position of an image on the optical bench by a pin is called the method of parallax.

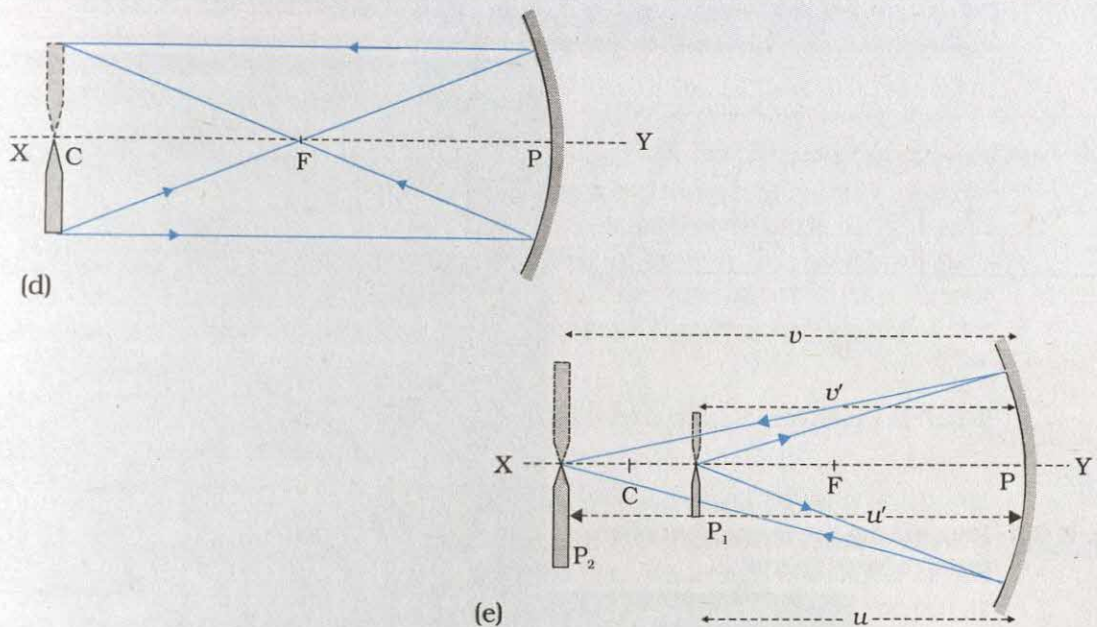


Fig. E 9.3 (d), (e) Ray diagram for finding focal length of a concave mirror

SIGN CONVENTION

1. All the distances are measured from the pole P of the mirror (or the optical centre of a lens).
2. The distance measured in the direction of propagation of incident rays are taken as positive and those measured in the opposite direction are taken as negative.
3. The heights measured upwards (above the principal axis of the mirror/lens) are taken as positive and the heights measured downwards are taken as negative (Fig. E 9.4).

Note: In the cartesian sign convention, the object is always placed to the left of the mirror (or the lens).

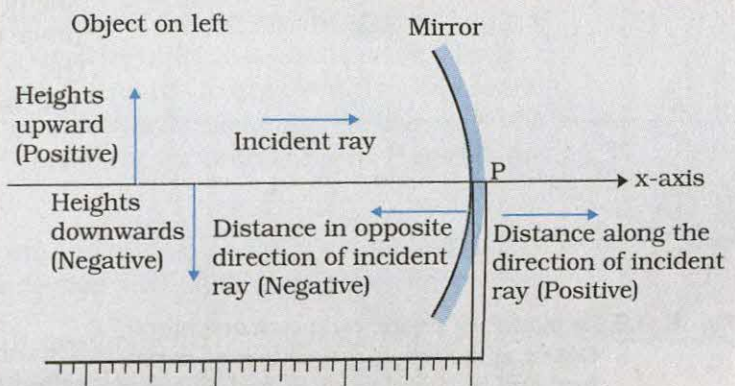


Fig. E 9.4 The cartesian sign convention

RAY TRACING IN SPHERICAL MIRRORS

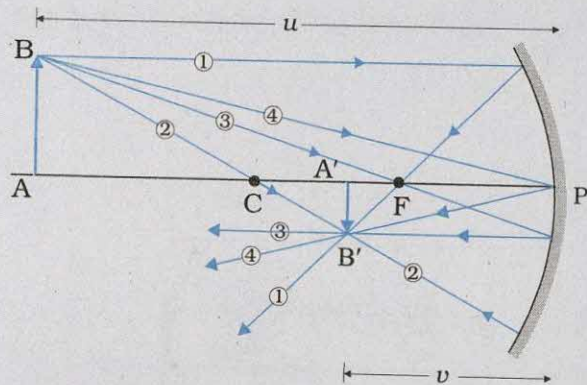


Fig. E 9.5 Ray tracing for image formation by a concave mirror

To locate the image, we need to trace only a few specific paths or rays (a minimum of two) as shown in Fig. E 9.5.

Conveniently, any two rays can be taken to locate the image.

1. An incident ray parallel to the principal axis of the mirror either passes through the principal focus F (concave mirror) or appears to be diverging from it (convex mirror).
2. An incident ray passing through the centre of curvature C (concave mirror) or appearing to pass through it (convex mirror), retraces its path i.e. reflected back along its original path. You must note that this ray is incident normal to the mirror.
3. An incident ray passing through the principal focus F (concave mirror) or appearing to pass through it (convex mirror) will be reflected from the mirror parallel to the principal axis.
4. An incident ray striking the pole P of the mirror is reflected at an angle equal to the angle of incidence with the principal axis.

PRINCIPLE

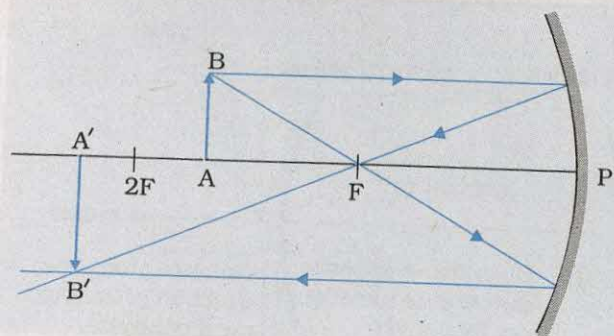


Fig. E 9.6 Formation of image by a concave mirror. Object is between the centre of curvature and principal focus F; real, inverted and magnified image is between the centre of curvature and infinity

For an object placed at a distance u from the pole of a concave mirror of focal length f , the image is formed at a distance v from the pole. The relation between these distances (for a concave mirror) is

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

or
$$f = \frac{uv}{u+v}$$

If an object (say, a pin) is placed in front of the reflecting surface of the concave mirror such that the object's position lies in between the principal focus of the mirror, F and the centre of curvature C, then a real, inverted and magnified image is formed in between the centre of curvature C of the mirror and infinity (Fig. E 9.6).

Thus, the image formed in such a case would be clearer and easier to be seen. The focal length of the mirror, using the above relation, can be determined by placing the object in between the point $2F$ and focus F .

PROCEDURE

1. Obtain approximate value of the focal length of concave mirror by focusing the image of a distant object. Obtain bright and clear image of a distant building or tree on a plane wall or a sheet of paper and measure the distance between the mirror and the image which gives the approximate focal length of the concave mirror.
2. Place the optical bench on a rigid table. Make it horizontal using a spirit level and levelling screws.
3. Clamp the concave mirror on an upright and mount it vertically near one end of the optical bench. Move an object pin P_1 on the optical bench back and forth so that its image is formed at the same height. Make slight adjustments of the height of the pin or the mirror inclination. This procedure ensures that the principal axis of the mirror is parallel to the optical bench.
4. Place another vertically mounted sharp and bright pin P_2 in front of the reflecting surface of the concave mirror. Adjust the pins P_1 and P_2 so that the height of the tips of these pins become equal to the height of the pole P of the mirror from the base of the optical bench [Fig. E 9.3(e)].
5. To determine index correction, a thin straight index needle is placed so that its one end A_1 touches the tip of the pin and the other end B_1 touches the pole P of the mirror. The positions of the uprights are read on the scale. Their difference gives the observed distance between tip of the pin and the pole of the mirror. Length of the needle A_1B_1 is measured by placing it on the scale which is the actual distance between the points in question. The difference between the two gives the correction to be applied to the observed distance. Find the index correction for both the pins P_1 and P_2 for all measurements.
6. Move the pin P_1 away from the mirror and place it almost at $2F$. An inverted image of same size as the pin should be visible.
7. Now place another pin P_2 on the bench, adjust its height to be almost the same as the earlier pin. Place a piece of paper on the tip of one pin, take this as the object pin.
8. Place the pin with paper at a distance lying between F and $2F$.
9. Locate the image of the pin using the other pin. Remember that parallax has to be removed between the image and the pin.

10. Note the values of u and v i.e., the distances of the object and image pins from the mirror respectively.
11. Repeat the experiment for at least five different positions of the object and determine the corresponding values of v . Record your observations in tabular form.
12. After doing index correction record the corrected values of u and v . Find the value of focal length, f .

OBSERVATIONS

1. Rough focal length of the concave mirror = ...cm
2. Actual distance of the object from the mirror using index needle, $l_o = \dots$ cm
3. Observed distance of the object from the mirror
= position of mirror upright – position of object pin upright on the scale, $l'_o \dots$ cm
4. Index correction for object distance, $e = \text{actual distance} - \text{observed distance}$.

$$= l_o - l'_o = \dots \text{cm}$$

Similarly for image pin

$$e_i = l_i - l'_i = \dots \text{cm}$$

Table E 9.1: Determination of u , v and f

Sl. No.	Position of			Observed u' (cm)	Observed v' (cm)	Corrected $u = u' + e$ (cm)	Corrected $v = v' + e_i$ (cm)	$f = \frac{uv}{u+v}$ (cm)	Δf (cm)
	Mirror M (cm)	Object pin P_1 (cm)	Image pin P_2 (cm)						
1									
2									
...									
6									
Mean									

CALCULATIONS

Calculate the corrected values of u and v and compute the value of f . Tabulate them and find the mean value of the focal length of the given concave mirror.

Error

$$\therefore \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{\Delta f}{f^2} = \frac{\Delta u}{u^2} + \frac{\Delta v}{v^2}$$

$$\text{or } \Delta f = f^2 \left[\frac{\Delta u}{u^2} + \frac{\Delta v}{v^2} \right]$$

RESULT

The focal length of the given concave (converging) mirror is $(f \pm \Delta f) = \dots \pm \dots \text{cm}$

Here f denotes mean value of the focal length and Δf is maximum of the six values of the error.

PRECAUTIONS

1. The uprights supporting the optical elements should be rigid and mounted vertically.
2. The object pin should be kept in between the centre of curvature and the focus of the mirror.
3. The aperture of mirror should be small otherwise the image formed will not be distinct.
4. Eye should be placed at a distance of distinct vision (25 cm) from the image needle.
5. The tip of the inverted image of the object pin must touch the tip of the image pin and must not overlap. It should be ensured while removing the parallax.
6. The image and the object pins should not be interchanged during the course of the experiment.
7. The corrected values of the distances u and v must be put in the formula for calculating f and then a mean value of f should be taken. Calculations for f must not be made using the mean values of u and v .
8. A white screen or plane background may be used for seeing the clear image of the pin.
9. Image of the Sun should not be seen directly as it may hurt your eyes.

SOURCES OF ERROR

1. An error may arise in the observations if the top of the optical bench is not horizontal and similarly if the tips of pins and pole of the mirror are not at the same horizontal level.
2. The concave mirror should be front-coated, otherwise multiple reflections will come from the reflecting surface of the mirror.

DISCUSSION

The image B' of the point B (Fig. E 9.6) will be at the point where two such rays either intersect or appear to be intersecting. The image of the bottom of the object A (lying on the principal axis) will lie on the principal axis itself such that the final image is perpendicular to the axis as the object.

SELF ASSESSMENT

1. A dentist uses concave mirror to see the tooth. In what way does it help the dentist?
2. Can you determine the focal length of the concave mirror if $u < f$?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Plot a graph of uv against $u + v$ with uv on y-axis and $u+v$ on x-axis. Determine f from the slope of the graph.
2. Using spherometer, determine the radius of curvature of the concave mirror and calculate its focal length ($f = R/2$).

EXPERIMENT 10

AIM

To find the focal length of a convex lens by plotting graphs between u and v or between $1/u$ and $1/v$.

APPARATUS AND MATERIAL REQUIRED

An optical bench, two sharp-edged needle (pins), convex lens of less than 20 cm focal length, three uprights (with clamps), index needle (may be a knitting needle), metre scale and spirit level.

TERMS AND DEFINITIONS

1. *Principal axis* of a lens is the line joining centre of curvature of the two surfaces.
2. *Optical centre* is the point, through which a ray passes undeviated through the lens.
3. *Principal focus* is the point where rays parallel to the principal axis focus after passing through the lens (convex) or appear to come from after passing through the lens (concave).
4. *Focal length* is the distance between optical centre of lens and focus.
5. *Intercepts of a graph*: If a graph cuts x-axis and y-axis, then lengths between origin and points of interception are intercepts of the graph.

GRAPHICAL METHOD FOR FINDING THE POSITION OF AN IMAGE FORMED BY THIN LENSES

The image formed by a thin lens can be located using graphical method by considering refraction of rays emanating from each point on the object. However, it is convenient to choose any two of the following three rays (Fig. E 10.1).

1. A ray from the tip of the object parallel to the principal axis of the lens that passes through the second principal focus F' (in a convex lens) or appears to diverge (in a concave lens) from the first principal focus F after refraction.
2. A ray from the tip of the object incident at the optical centre, passes through the lens undeviated. This is because near its centre, the lens behaves like a thin glass slab.
3. A ray of light from the same point on the object that passes through the first principal focus F (for a convex lens) or appearing to pass through F' (for a concave lens) emerges parallel to the principal axis after refraction.

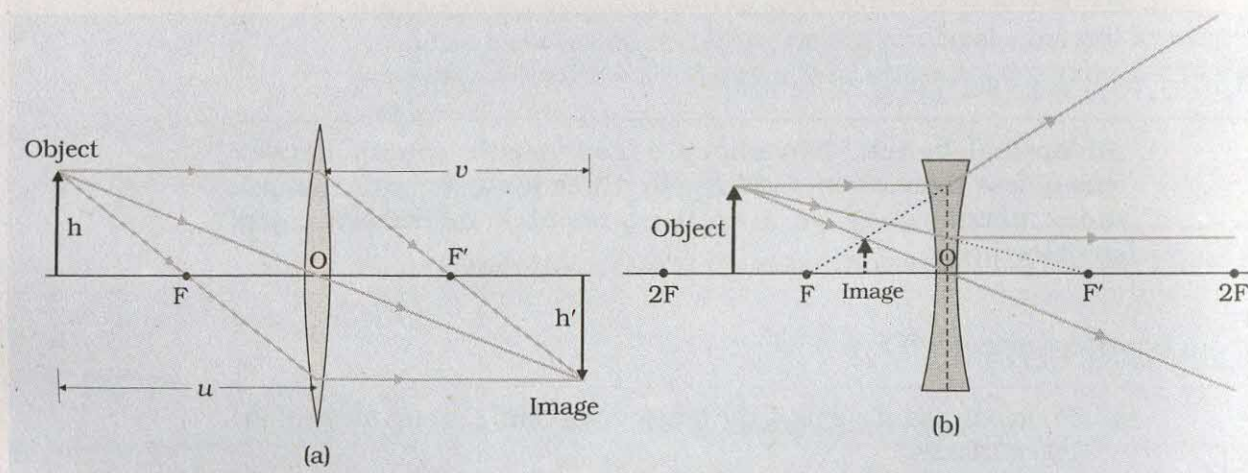


Fig. E 10.1 Ray tracing for locating the image formed by (a) convex lens and (b) concave lens.

P RINCIPLE

For an object placed at a distance u from the optical centre of a thin convex lens of focal length f , a real and inverted image is formed on the other side of the lens at a distance v from the optical centre. The relation between these distances is:

(E 10.1)

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

According to the new cartesian sign convention (see *Physics Textbook, NCERT, 2007, Class XII, Part-II p. 311*), u is negative but v is positive [Fig. E 10.2 (a) and (b)]. Therefore the Eq. (E 10.1) takes the following form for magnitudes of u and v .

(E 10.2)

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

$$\text{or, } f = \frac{uv}{u+v}$$

(E 10.3)

In this result the positive values of u and v are substituted.

Eq. (E 10.2) shows that $\frac{1}{v}$ versus $\frac{1}{u}$ graph is a straight line of negative slope. If $\frac{1}{v}$ equals zero or $\frac{1}{u}$ equals zero, then respectively $\frac{1}{u} = \frac{1}{f}$ or $\frac{1}{v} = \frac{1}{f}$. The intercepts of the graph on both axes are $\frac{1}{f}$. Graph of u versus v is a hyperbola. When $u = v$, then each equals $2f$. Eq. (E 10.3) shows that values of u and v are interchangeable.

When an object (say, a pin) is placed in front of a thin convex lens at a distance equal to $2f$, a real and inverted image of same size as that of the object is formed at a distance equal to $2f$ on the other side of the lens [Fig. E 10.2(a)]. If the object's position lies in between distance $2f$ and distance f from the optical centre of the lens then a real, inverted and magnified image is formed at a point beyond $2f$ from the optical centre on the other side of the lens [Fig. E 10.2(b)].

Thus, by measuring the distances u and v , the focal length of the convex lens can be determined using Eq. (E 10.3). The focal length of the lens may also be determined by plotting graphs between u and v or between $1/u$ and $1/v$.

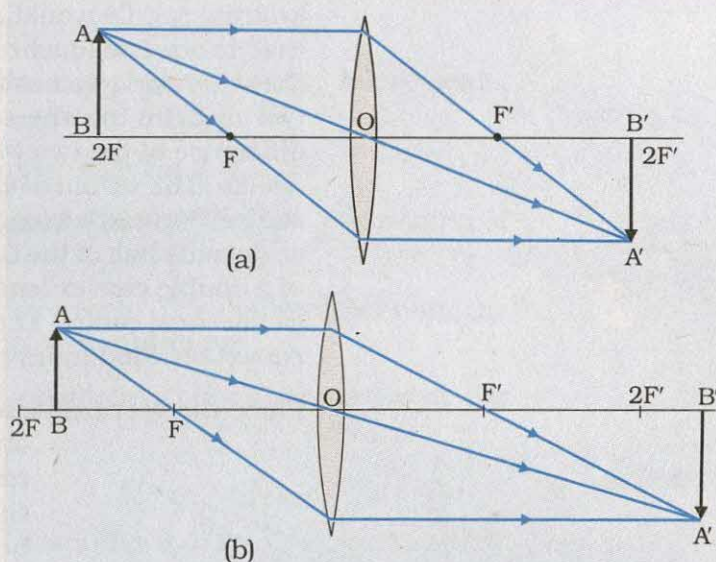


Fig. E 10.2 (a), (b) Formation of image by a convex lens (a) $u = 2f$ and (b) $2f > u > f$.

PROCEDURE

1. Obtain approximate value of the focal length of the thin convex lens by focusing the image of a distant object. It can be found by obtaining a sharp image of the Sun or a distant tree on a screen, say a plane wall, or a sheet of paper placed on the other side of the lens and measuring the distance between the lens and the image with a scale. This distance is a rough estimate of the focal length, f of the convex lens.

Note: Do not look at the image of Sun directly as it may hurt your eyes.

- Place the optical bench on a rigid table or on a platform, and using the spirit level, make it horizontal with the help of levelling screws provided at the base of the bench.
- Clamp the convex lens on an upright and mount it vertically almost near to the middle of the optical bench such that its principal axis is parallel to the optical bench. In this position, the lens would lie in a plane perpendicular to the optical bench.
- For the determination of the index correction, bring a mounted pin close to the lens. Adjust the index needle (a sharp-edged knitting needle would also serve the purpose) horizontally such that its one end touches one of the curved surfaces of the lens and the other end touches the tip of the pin. Note the positions of the two uprights on the scale provided on the optical bench. The difference of the two would give the *observed length* of the index needle. The *actual length* between the tip of the pin and optical centre O would be length of the index needle (as measured by a scale) plus half of the thickness of the lens because optical centre of a double convex lens with surfaces of equal curvature is at its geometrical centre. The difference of the two lengths is the *index correction*. Find index correction for both the pins.

- Place the vertically mounted sharp pins P and P' (Fig. E 10.3) on left and right hand sides of the lens respectively. Adjust the pins P and P' so that the heights of the tips of these pins become equal to the height of the optical centre O of the lens from the base of the optical bench. Let the pin P (placed on left hand side of the lens) be the object pin and the pin P' (lying on right hand side) be the image pin. Put a small piece of paper on one of the pins (say on image pin P') to differentiate it from the object pin P'.

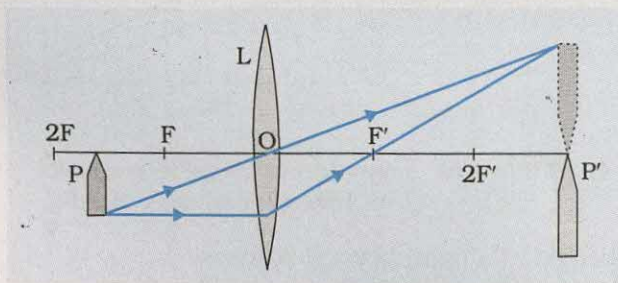


Fig. E 10.3 The ray diagram for finding the focal length of a convex lens.

- Displace the object pin P (on left side of the lens) to a distance slightly less than $2f$ from the optical centre O of the lens (Fig. E 10.3). Locate the position of the real and inverted image on the other side of the lens above the image pin P'.
- Using the method of parallax, adjust the position of the image pin P' such that the image of the object pin P coincides with the image pin P'.

Note: As the value of u changes from $2f$ to f , v changes from $2f$ to infinity. Since the values of u and v are interchangeable, i.e., the object and image are two conjugate points, therefore it is clear that complete range of values for both u and v between f and infinity are obtained for a movement of the object pin over the range $2f$ to f .

8. Note the upright position of the object pin, convex lens and image pin on the optical bench and record the readings in an observation table.
9. Move the object pin P closer to the optical centre O of the lens (say by 2 cm or 3 cm). Repeat the experiment and record at least six sets of readings for various distances of object pin between f and $2f$ from the lens.

OBSERVATIONS

1. Approximate focal length of the convex lens = ... cm
2. Length of the index needle as measured by the metre scale, $L_0 = \dots$ cm
3. Thickness of the thin convex lens (given), $t = \dots$ cm
4. Actual length between the optical centre O of the lens and tip of the pin, $l_0 = L_0 + t/2 = \dots$ cm
5. Observed length of the index needle, $l'_0 =$ Distance between the centre of convex lens and tip of the object pin
 = Position of lens upright – position of object pin upright on the scale.
 = ... cm – ... cm = ... cm
6. Index correction for object distance, $e_o = l_0 - l'_0 = \dots$ cm; similarly for image pin, $e_i = l_i - l'_i = \dots$ cm

Table E 10.1: Determination of u , v and f

Sl. No.	Lens upright a (cm)	Object pin upright b (cm)	Image pin upright c (cm)	Observed $u = a - b$ (cm)	Observed $v = a - c$ (cm)	Corrected $u =$ Observed $u + e_o$ (cm)	Corrected $v =$ Observed $v + e_i$ (cm)	$\frac{1}{u}$ cm^{-1}	$\frac{1}{v}$ cm^{-1}	$f = \frac{uv}{u+v}$ cm	Δf (cm)
1											
2											
...											
6											
Mean											

CALCULATIONS

- A. Calculate the corrected values of u and v . Compute the value of f using Eq. (E 10.3). Tabulate them in the table and find the mean value of the focal length of the given convex lens.

Error

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\text{or } \frac{\Delta f}{f^2} = \frac{\Delta u}{u^2} + \frac{\Delta v}{v^2}$$

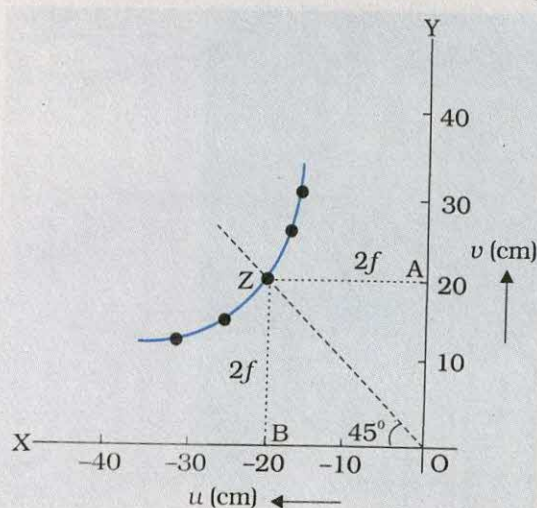
$$\Delta f = f^2 \left[\frac{\Delta u}{u^2} + \frac{\Delta v}{v^2} \right]$$

Maximum of six values of Δf is to be reported with the result as the experimental error.

CALCULATION OF FOCAL LENGTH BY PLOTTING GRAPHS

(A detailed method of plotting graphs has been illustrated in Chapter 1 Article 1.8 (p. no. 15).

- B. $u - v$ Graph: Take u along x-axis and v along y-axis. Scales of x- and y-axis should be same. Draw a hyperbola curve for various values of u and v (Fig. E 10.4). Note that six sets of readings for u between f and $2f$, give you 12 points on the graph by interchanging values of u and v .



The point $u = 2f$; $v = 2f$ is shown as point Z on $u - v$ graph (Fig. E 10.4). The point Z is the point of intersection of a line OZ bisecting the angle $\angle XOY$ with hyperbola. Draw two lines AZ and BZ perpendicular to Y- and X-axis, respectively. The lengths AZ and BZ are both equal to distance $2f$. Thus by plotting the $u - v$ graph, the focal length of the lens can be obtained.

Distance OA ($= 2f$) on y-axis = ... cm

Distance OB ($= 2f$) on x-axis = ... cm

Mean focal length of the convex lens, f

Fig. E 10.4 u versus v graph for convex lens = $\frac{OA + OB}{4} = \dots$ cm

- C. $1/u - 1/v$ graph: Draw a straight line graph by plotting $1/u$ along the X-axis and $1/v$ along the Y-axis (Fig. E 10.5). Both the intercepts OA' (on y-axis) and OB' (on X-axis) will be equal to distance $1/f$.

Intercept OA' ($= 1/f$) on y-axis
 $= \dots \text{cm}^{-1}$

Intercept OB' ($= 1/f$) on x-axis
 $= \dots \text{cm}^{-1}$

Mean focal length (f) of the convex

$$\text{lens} = \frac{2}{OA' + OB'} = \dots \text{cm}.$$

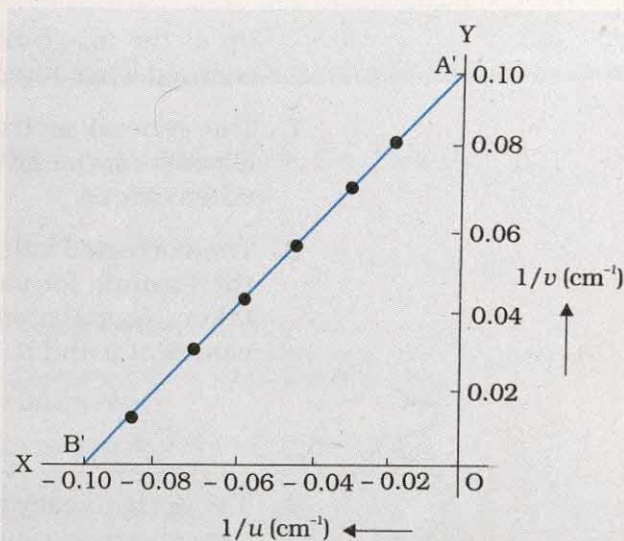


Fig. E 10.5 $1/u$ versus $1/v$ graph for a convex lens (not to scale).

RESULT

The focal length of the given converging thin convex lens:

- from calculations as shown in Observation Table E10.1
 $f \pm \Delta f = \dots \text{cm}$ (here f is mean value of the focal length)
- from $u - v$ graph $= \dots \text{cm}$, and
- from $1/u - 1/v$ graph $= \dots \text{cm}$.

PRECAUTIONS

- The uprights supporting the optical elements should be rigid and mounted vertically.
- The aperture of the lens should be small otherwise the image formed will not be distinct.
- Eye should be placed at a distance more than 25 cm from the image needle.
- An error may arise in the observations if the top of the optical bench is not horizontal and similarly if the tips of pins and optical centre of the lens are not at the same horizontal level.
- The image and object needles should not be interchanged during the performance of the experiment, as this may cause change in index corrections for object distance and image distance.
- The tip of the inverted image of the object needle must touch the

tip of the image needle and must not overlap. This should be ensured while removing the parallax.

7. The general instructions to be followed in all optical bench experiments (as given in the description of optical bench) must be taken care of.
8. The corrected values of the distances u and v must be put in the formula for calculating f and then a mean of f should be taken. Calculations for f must not be made using the mean values of u and v .

SOURCES OF ERROR

1. The uprights may not be vertical.
2. Parallax removal may not be perfect.
3. If the knitting needle or index rod for finding index correction is not sharp like a needle, its length may not be accurately found on scale.

DISCUSSION

In plotting $1/v$ versus $1/u$ graph, if scales for the two axes are not same, then the straight line graph may (rather will) not be at 45° to x-axis. This may result in confusions and error in drawing the graph. Keeping the scale same and drawing the best fit graph at 45° to x-axis is the best method. Then, due to inherent errors in measurement $1/f$ on both axes may be a bit too large or a bit too small.

SELF ASSESSMENT

1. Draw the ray diagram for image formation in case of a convex lens for position of object varying from infinity to optical centre.
2. What are the differences between the image formed by a convex lens and a concave lens?
3. How does the focal length of a thick convex lens differ from that of a thin lens?
4. How can you recognise a convex lens, a circular glass slab and a concave lens, without touching them?
5. Where does the centre of curvature of the plane surface of a plano-convex lens lie?
6. Define the principal axis of a plano-convex lens?

7. How does the focal length of a convex lens change if it is dipped in water?
8. What is the relation between focal length and radius of curvature of a plano-convex lens?
9. Can a virtual image produced by a lens be inverted?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Draw a graph by plotting $u v$ along y-axis and $u + v$ along x-axis. Determine focal length f of the convex lens from the slope.
2. **EFFECT OF MEDIUM ON FOCAL LENGTH**
You have an aquarium, an open window at some distance from it, and a magnifying glass of 50 mm diameter. With your 30 cm scale find the rough focal length of the magnifying glass in air. Then dip it in water by left hand and a white plastic bag (folded with a 5 cm $\times$ 5 cm card in it to make a white screen) by right hand. Focus image of a distant object on the screen by adjusting the position of the screen. Is the rough focal length in water bigger or smaller than that in air? Let a friend measure the focal length in water and find the ratio of the two.
3. **MEASURING LENGTH OF THE FILAMENT OF A CLEAR ELECTRIC LAMP**
You cannot put the scale behind and in contact with the filament to measure its length. Of course you can do this measurement by vernier microscope. But can it be done by a simple convex lens and a scale only? You can also add things like clamp stand etc, as per needs of the experiment. Can you also measure the dark (cool) gap between adjacent segments of the filament of the lamp?

EXPERIMENT 11

AIM

To find the focal length of a convex mirror using a convex lens.

APPARATUS AND MATERIAL REQUIRED

An optical bench with uprights for holding lens, mirror and two needles, two needles (pins), a thin convex lens, a convex mirror, index needle (may be a knitting needle or a pencil sharply pointed at both ends), a metre scale and a spirit level.

PRINCIPLE

Fig. E 11.1 illustrates the formation of image of an object AB by a convex mirror MM' (having a small aperture) in two different situations. The image formed by a convex mirror is virtual and erect. Therefore, its focal length cannot be determined directly. However, it can be determined by introducing a convex lens in between the object and the convex mirror (Fig. E 11.2).

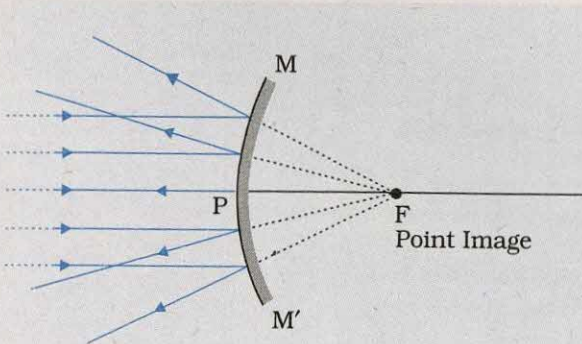


Fig. E 11.1(a) Object is at infinity. A highly diminished and point image is located at the focus behind the convex mirror

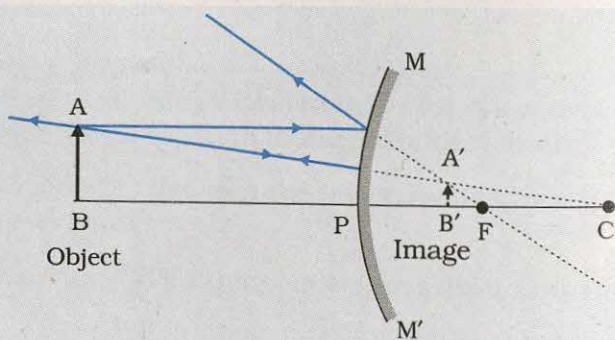


Fig. E 11.1(b) Object is in front of the mirror. A diminished virtual image is produced between the pole and focus behind the mirror

An object AB is placed at point P' in front of a thin convex lens such that its real, inverted and magnified image A'B' is formed at position

C on the other side of the lens [Fig. E 11.2(b)]. Now a convex mirror is introduced between the convex lens and point C and so adjusted that the real and inverted image $A'B'$ coincides with the object AB at point P' [Fig. E 11.2 (a)]. This is possible if the light rays starting from the tip of the object, after passing through the lens, fall normally on the reflecting surface of the convex mirror and retrace their path. Any normal ray (perpendicular) to a spherical surface has to be along the radius of that sphere so that point C must be the centre of curvature of the convex mirror. Therefore, the distance PC is the radius of curvature R and half of it would be the focal length of the convex mirror. That is,

$$f = \frac{PC}{2} = \frac{R}{2}$$

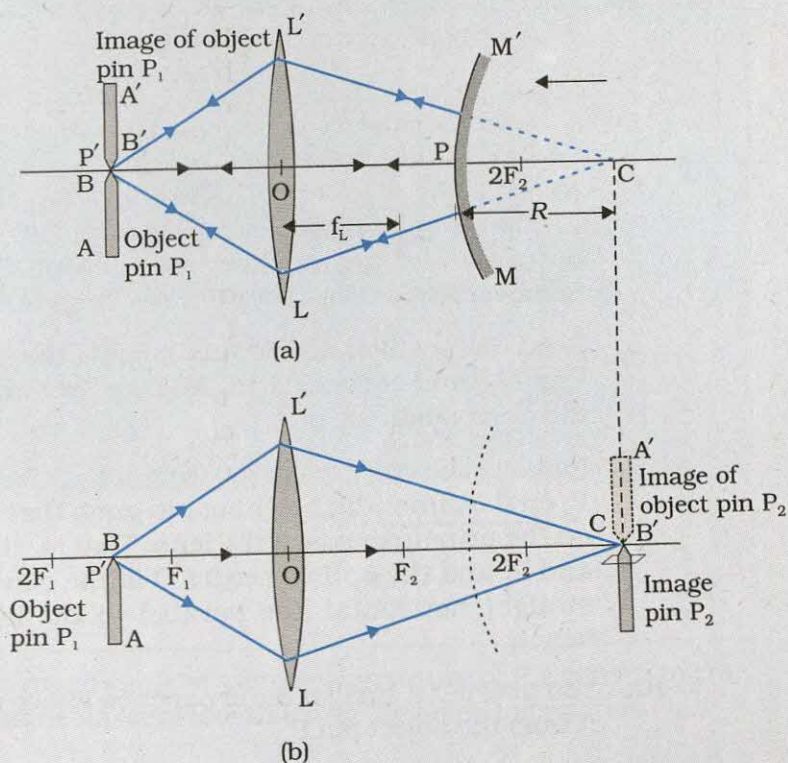


Fig. E 11.2 Image formed by (a) convex mirror and convex lens-image $A'B'$ coincides with the object AB at P' (b) convex lens- image is inverted and magnified

PROCEDURE

1. In case, if the focal length of the given thin convex lens is not known then approximate value of its focal length should be estimated first.

2. Place the optical bench on a rigid table or on a platform. Using the spirit level, make it horizontal with the help of levelling screws provided at the base of the bench.
3. Place the uprights mounted with pin P_1 (object pin), convex lens LL' , and convex mirror MM' on the horizontal optical bench [Fig. E 11.2(a)].
4. Check that the lens, mirror, and pin P_1 are vertically placed on the optical bench. Also verify that the tip of the pin, optical centre O of the convex lens LL' , and pole P' of the convex mirror MM' lie on the same horizontal straight line, parallel to the optical bench.
5. Determine the index correction between upright holding of the convex mirror and image pin respectively, using an index needle.
6. Place the object pin P_1 from the convex lens LL' at a distance slightly greater than the focal length of the lens.
7. Adjust the position of the convex mirror MM' till the light rays reflected back from the mirror pass through the lens and form a real and inverted image coinciding with the object pin P_1 , as shown in Fig. E 11.2 (a). This occurs when the rays starting from the tip of pin P_1 , after passing through the lens strike the mirror normally and are reflected back along their original paths. Remove the parallax between the image and object pins.
8. Read the position of uprights holding the object pin P_1 , convex lens LL' , and convex mirror MM' and record the observations in the observation table.
9. Remove the convex mirror from its upright and fix image pin P_2 on it. Adjust the height of pin such that the tip of it also lies on the principal axis of the lens. That is, the tips of the pins P_1 and P_2 and the optical centre O of the convex lens, all lie on a straight horizontal line parallel to the length of the optical bench.
10. You may put a small piece of paper on image pin P_2 to differentiate it from the object pin P_1 .
11. Using the method of parallax and without changing the position of lens LL' and object pin P_1 , adjust the position of image pin P_2 on the other side of the lens so that it coincides with the real and inverted image of the object pin P_1 formed by the convex lens [Fig. E 11.2(b)]. Note the position of the image pin.
12. Repeat the experiment by changing the separation between the pin P_1 and lens LL' and the mirror MM' . In this manner, take five sets of observations.

OBSERVATIONS

1. Focal length of the convex lens, f (estimated/given) = ... cm
2. Actual length of the index needle, l = ... cm
3. Observed length of the index needle l'
= Position of mirror upright – position of pin upright on the scale
= ... cm
4. Index correction, e = Actual length – observed length ($l - l'$) = ... cm

Table E 11.1: Determination of radius of curvature of convex mirror, R

Sl. No.	Upright position of				Observed $R' = c - d$ (cm)	Corrected R Observed $R' + e$ (cm)	Focal length f (cm)	Δf (cm)
	Object pin P_1 a (cm)	Convex lens LL' b (cm)	Convex mirror MM' c (cm)	Image pin P_2 d (cm)				
1								
2								
...								
5								
Mean								

CALCULATIONS

Calculate the mean value of radius of curvature of the convex mirror, R , and determine its focal length using the following relation

$$f = \frac{R}{2} = \dots \text{ cm}$$

Error

$$f = \frac{R' + l}{2} = \frac{(c - d) + (l - l')}{2}$$

$$\frac{\Delta f}{f} = \frac{\Delta c}{c} + \frac{\Delta d}{d} + \frac{\Delta l}{l} + \frac{\Delta l'}{l'}$$

when Δc , Δd , Δl and $\Delta l'$ are the least counts of the measuring instruments. Maximum of the five values of Δf is to be reported with the result as the experimental error.

RESULT

The focal length of the given convex mirror is $(f \pm \Delta f) \dots \pm \dots$ cm.

Here f is mean value of the focal length.

PRECAUTIONS

1. The uprights supporting the pins, lens and mirror must be rigid and mounted vertically.
2. The apertures of the given convex lens and convex mirror should be small, otherwise the image formed will be distorted.
3. Eye should be placed at a distance of about 25 cm or more from the image pin.
4. Optical bench should be horizontal. The tips of pins, centre of convex lens and pole of the mirror should be at the same horizontal level.

SOURCES OF ERROR

1. The tip of the inverted image of the object pin should just touch the tip of the image pin and must not overlap. This should be ensured while removing the parallax.
2. Personal eye defects may make removal of parallax tedious.
3. The convex mirror should preferably be front-coated. Otherwise multiple reflections may take place.

DISCUSSION

It may not be possible to perform this experiment with just any convex lens. The focal length of the lens used in this experiment should neither be too small nor too large. Why?

SELF ASSESSMENT

1. If focal length of the concave mirror is determined, by using convex lenses of different focal lengths, do you expect any change in the result? If yes, what type of change? If not, why not?

2. How will the result change if a convex lens of different refractive indices were used?
3. If the convex lens selected for the experiment has focal length less than that of the convex mirror, how would this selection limit the experiment?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Repeat the experiment by using convex lenses of different focal lengths. Compare and analyse the results.
2. Repeat the experiment by using convex mirrors of different focal lengths with the help of the same convex lens. Discuss the results.

EXPERIMENT 12

AIM

To find the focal length of a concave lens with the help of a convex lens.

APPARATUS AND MATERIAL REQUIRED

An optical bench with uprights for holding the lenses and two needles, a thin concave lens, a convex lens of focal length (~ 15 cm) smaller than that of the concave lens, index needle (may be a knitting needle), a metre scale and a spirit level.

PRINCIPLE

Figs. E 12.1 (a),(b),(c) and (d) illustrate the formation of image $A'B'$ of an object AB by a concave lens. It is clear that the image formed by a

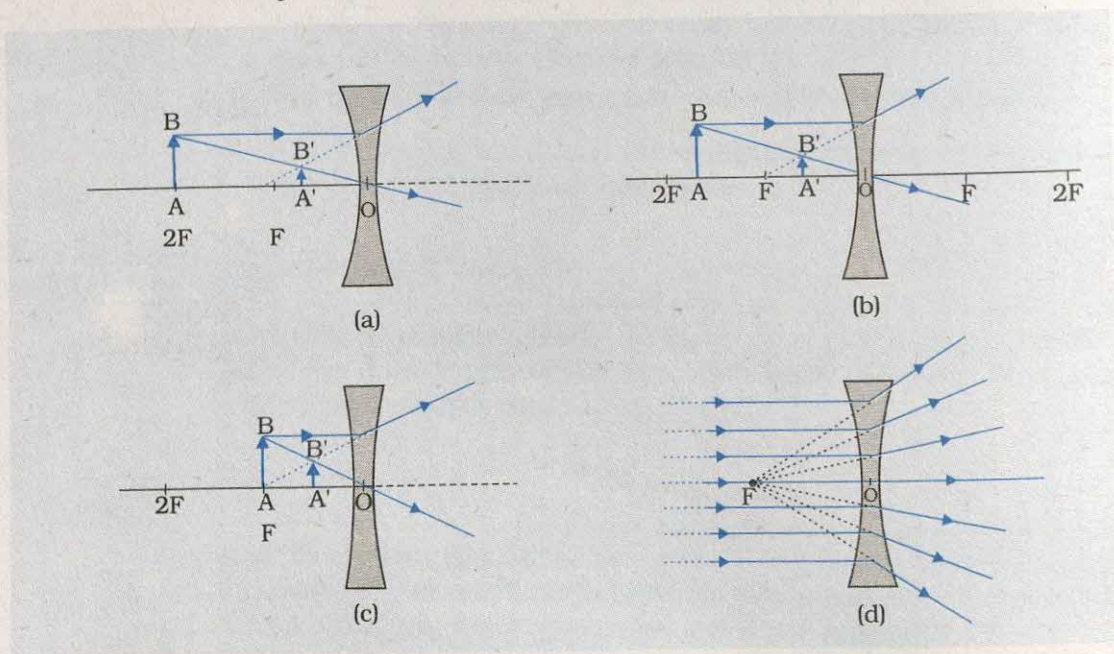


Fig. E 12.1 (a),(b),(c), (d) The images formed by a concave lens for different object positions

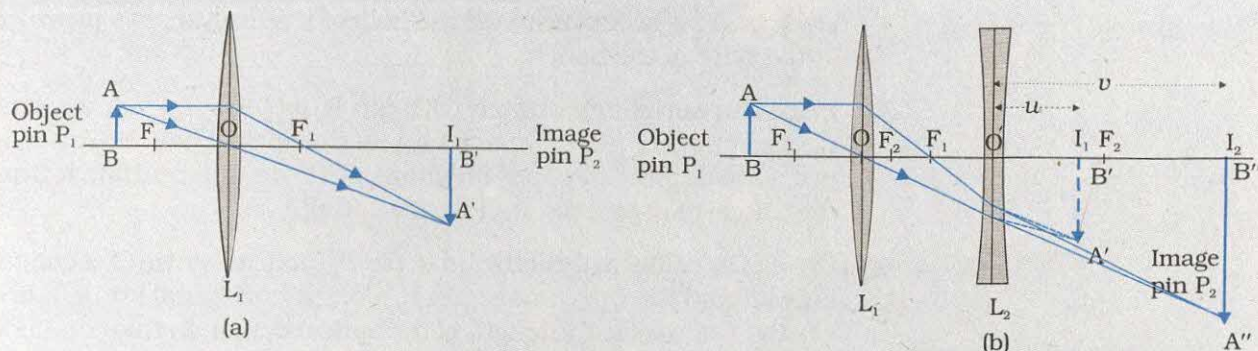


Fig. E 12.2 Formation of image (a) by a convex lens; and (b) by a combination of convex lens and concave lens

concave lens is always virtual and erect in these cases. Therefore, its focal length cannot be determined directly. However, it can be determined indirectly by introducing a convex lens in between the object and the concave lens and producing a real image as illustrated in Fig. E12.2.

A convex lens L_1 converges the light rays starting from the object AB to form a real and inverted image $A'B'$ at position I_1 [Fig. E 12.2(a)]. If a concave diverging lens L_2 is inserted between the lens L_1 and point I_1 as shown in Fig. E 12.2 (b), for concave lens L_2 image $A'B'$ behaves as virtual object. A real and inverted image $A''B''$ is formed at point I_2 by the diverging lens L_2 . Thus, for the concave lens L_2 the distances $O'I_1$ and $O'I_2$ would be the distances u and v , respectively. It is important to note that the focal length of convex lens L_1 must be smaller than the focal length of the concave lens L_2 . The second image $A''B''$ is formed only when the distance between lens L_2 and first image $A'B'$ is less than the focal length of L_2 .

The focal length of the concave lens L_2 can be calculated from the relation

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad \text{or} \quad f = \frac{uv}{u-v} \quad (\text{E 12.1})$$

Here for the concave lens both distances u and v are positive and since u will be found to be less than v , f will always be negative.

PROCEDURE

1. In case, if the focal length of the given thin convex lens is not known then rough value of its focal length (f_L) should be estimated first to ensure that its focal length is less than that of the concave lens.

2. Place the optical bench on a rigid platform and using the spirit level, make it horizontal with the help of levelling screws provided at the base of the bench.
3. Place the uprights mounted with pin P_1 (object pin), convex lens L_1 , and another pin P_2 (image pin) on the optical bench. You may put a small piece of paper on image pin P_2 to differentiate it from the image of object pin P_1 [Fig. E 12.2(a)].
4. Check the collinearity of the tip of pin P_1 , optical centre O of convex lens L_1 , and the tip of image pin P_2 along a horizontal straight line which is parallel to the length of the optical bench. In this condition the planes of lens and both the pins would be perpendicular to the axis of the lens.
5. For the determination of the index correction, bring a mounted pin close to the concave lens L_2 . Adjust the index needle (a sharp-edged knitting needle would also serve the purpose) horizontally such that its one end touches one of the curved surfaces of the lens and the other end touches the tip of the pin. Note the positions of the two uprights on the scale provided on the optical bench. The difference of the two would give the *observed length* of the index needle. The *actual length* between the tip of the pin and optical centre O' of the lens L_2 would be length of the index needle (as measured by a scale) plus half of the thickness of the lens at its optical centre. The difference of the two lengths is the index correction.

(If the concave lens is thin at the centre, its thickness at the centre can be ignored).
6. Separate the object pin P_1 from the convex lens by a distance slightly greater than the focal length f_L of the lens.
7. Locate its real and inverted image at point I_1 on the other side of the lens by removing the parallax between the image pin P_2 and image of the object pin P_1 [Fig. E 12.3(a)].
8. Read the positions of the uprights holding the object pin P_1 , convex lens L_1 , and image pin P_2 (i.e. point I_1). Record these observations in Table E 12.1.
9. From now on, do not change the position of the convex lens L_1 and the position of the object pin P_1 . Insert the concave lens L_2 in between the convex lens L_1 and image pin P_2 . Now the image of object pin will shift further from the convex lens L_1 to a point I_2 (say). Adjust the position of the concave lens so that the point I_2 is sufficiently away from the point I_1 .
10. In case the image formed by the combination of convex and concave lenses is not distinctly visible, try to see it on moving the concave lens nearer to the point I_1 and to locate the image by using a pencil

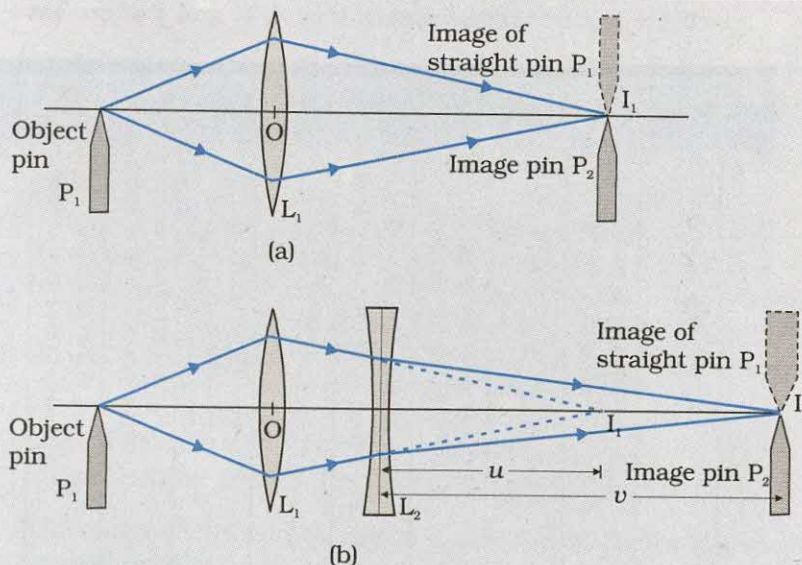


Fig. E 12.3 Focal length of concave lens with the help of convex lens

held in hand, and keeping the image pin P_2 at point I_1 as a guide to decide which way to shift the concave lens L_2 . After having seen the clear image at point I_2 and ensured that it lies within the range of the optical bench, move image pin P_2 to locate the image (or point I_2) more accurately using the method of parallax [Fig. E 12.3(b)]. Since the image forming at I_2 is quite enlarged, it can be blurred.

11. Note the position of uprights holding the concave lens and image pin P_2 , i.e., point I_2 . Note the readings in the Observation Table.
12. Change the position of upright holding the object pin P_1 and repeat the steps 6 to 10. Take five sets of observations.

OBSERVATIONS

1. Focal length of the convex lens, $f_L = \dots$ cm
2. Length of the index needle as measured by the scale, $s = \dots$ cm
3. Thickness of the thin concave lens (given) at its optical centre, $t = \dots$ cm
4. Actual length between the optical centre O of the lens and tip of the pin, $l = s + t/2 = \dots$ cm
5. Observed length of the index needle, l'
 = Distance between the pole of the lens and tip of the pin
 = Position of lens upright - position of pin upright on the scale
 = $\dots$ cm

Table E 12.1: Determination of u , v , and f of concave lens

Sl. No.	Position of										
	Object pin upright P_1 , a (cm)	Convex lens L_1 upright, b (cm)	Image formed by L_1 , point I_1 , c (cm)	Concave lens L_2 upright, d (cm)	Image formed by L_1 and L_2 , point I_2 , g (cm)	Observed u = $c - d$ (cm)	Observed v = $g - d$ (cm)	Corrected u = Observed $u + e$ (cm)	Corrected v = Observed $v + e$ (cm)	$f = uv/(u - v)$ (cm)	Δf (cm)
1											
2											
...											
5											
Mean											

 6. Index correction, $e = l - l' = \dots$ cm

CALCULATIONS

 Find the focal length of the concave lens using the formula $f = \frac{uv}{u - v}$

Error

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

$$\frac{\Delta f}{f^2} = \frac{\Delta v}{v^2} + \frac{\Delta u}{u^2}$$

$$\Delta f = f^2 \left[\frac{\Delta v}{v^2} + \frac{\Delta u}{u^2} \right]$$

where Δu , Δv represent least counts of the measuring scale. Values of u , v , f are to be taken from the Observation Table. Maximum of the five values of the error Δf is to be reported with the result as error.

RESULT

The focal length of the given concave lens is $(f \pm \Delta f) = \dots \pm \dots \text{cm}$.

PRECAUTIONS

Here f is mean value of the focal length.

1. The concave lens must be placed near the convex lens. In fact, the second image I_2 is formed only when the distance between concave lens L_2 and first image I_1 (which acts as virtual object for the concave lens) is less than the focal length of the concave lens.
2. Since the image formed at I_2 is quite enlarged, it can be blurred. Therefore, it would be preferable to use a thin and sharp object pin and shine it with light using a lighted electric bulb.
3. The convex lens and the pin P_1 must not be disturbed during the second part of the experiment.
4. A diminished, real and inverted image of the image pin P_2 might also be formed by the light rays reflecting from the concave surface of the lens L_2 . It should not be confused with the bold and bright image formed by the combination of convex and concave lenses.
5. Index correction/ bench correction for u and v should be made.

SOURCES OF ERROR

1. If tip of object pin and optical centre of the lens are not aligned properly (if not brought at the same horizontal level), image tip and image of object pin tip will not touch each other. There may be some gap between the two or there could be overlap between the two. In such situations, there can be error in removing parallax and it will lead to errors in the result.
2. For greater accuracy we should use sharply pointed object pin.

DISCUSSION

1. As concave lens diverges the rays, the image formed by a concave lens alone will not be real and cannot be taken on a screen. To converge these diverging rays to form a real image, convex lens is used.
2. Diverging rays from concave lens can be made to fall normally on a concave mirror to get the real image formed at the point where object is placed. Hence, the focal length of the concave lens can be found by using a concave mirror also.

3. Since the image I_2 is quite enlarged, it can get blurred by chromatic aberration of the two lenses. Thus it is better to put a screen behind object pin P_1 and thus do the entire experiment with one colour of light instead of with white light. For the same reason, pin P_1 should be quite thin and sharp compared to pin P_2 .

SELF ASSESSMENT

1. In this experimental setup the combination of concave lens and convex lens separated by a distance d behaves as a single lens of focal length F . Check the relation $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$ for any one of the observations.
2. Calculate f by interchanging the value of u and v and compare it with the experimentally determined value of f .

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Plot a graph of uv against $u-v$ with uv on y-axis and $u-v$ on x-axis. Determine f from the slope of the graph.
2. Repeat the experiment by using concave and convex lenses of different focal lengths, compare and analyse the results.

EXPERIMENT 13

AIM

To determine the angle of minimum deviation for a given glass prism by plotting a graph between the angle of incidence and the angle of deviation.

APPARATUS AND MATERIAL REQUIRED

Drawing board, triangular glass prism, metre scale, alpins, cellotape/drawing pins, graph paper, protractor, white paper sheets.

PRINCIPLE

A triangular prism has three rectangular lateral surfaces and two triangular bases. The line along which any two faces (refracting surfaces) of the prism meet is the refracting edge of the prism and the angle between them is the angle of the prism. For this experiment, it is convenient to place the prism with its rectangular surfaces vertical. The principal section ABC of the prism is obtained by a horizontal plane perpendicular to the refracting edge (Fig. E 13.1).

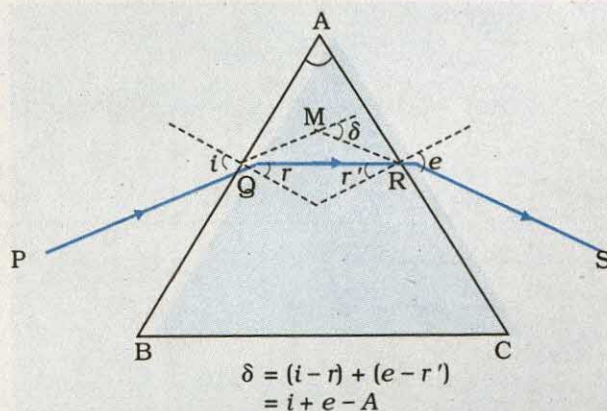


Fig. E 13.1 Refraction of light through a glass prism

A ray of light PQ (from air to glass) incident on the first face AB at an angle i is refracted at an angle r along QR and finally, emerges along RS. The dotted lines in the figure represent the normal to the surfaces. The angle of incidence (from glass to air) at the second face AC is r' and the angle of refraction (or emergence) is e . The angle between the direction of incident ray PQ (produced forward) and the direction of emergent ray RS (produced backward) is the angle of deviation δ .

From geometrical considerations we have

(E 13.1)

$$r + r' = A$$

(E 13.2)

$$\delta = (i - r) + (e - r') = i + e - A$$

At the position of the prism for minimum deviation δ_m , the light ray passes through the prism symmetrically, i.e. parallel to the base so that when

$$\delta = \delta_m, i = e \text{ which implies } r = r'.$$

The advantage of putting the prism in minimum deviation position is that the image is brightest in this position.

PROCEDURE

1. Fix a white sheet of paper on a drawing board with the help of cellotape or drawing pins.
2. Draw a straight line XY, using a sharp pencil nearly in the middle and parallel to the length of the paper.
3. Mark points $O_1, O_2, O_3, \dots$ on the straight line XY at suitable distances of about 8 to 10 cm and draw normals $N_1 O_1, N_2 O_2, N_3 O_3, \dots$ on these points (Fig. E 13.2).

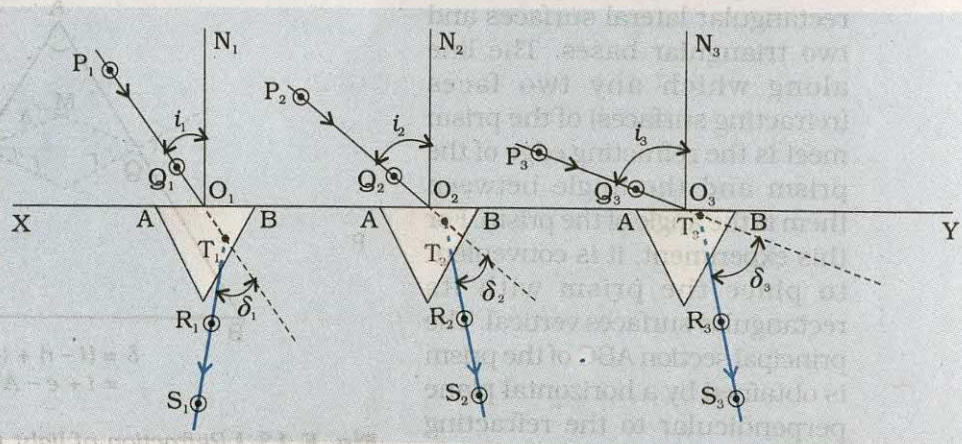


Fig. E 13.2 Refraction of light through a glass prism for various angles of incidence

4. Draw straight lines, $P_1 O_1, P_2 O_2, P_3 O_3, \dots$ corresponding to the incident rays making angles of incidence at $35^\circ, 40^\circ, 45^\circ, 50^\circ, \dots 60^\circ$ respectively with the normals, using a protractor. Write the values of the angles $\angle P_1 O_1 N_1, \angle P_2 O_2 N_2, \angle P_3 O_3 N_3, \dots$ on the white paper sheet (Fig. E 13.2).
5. Place the prism with its refracting face AB on the line XY with point O_1 in the middle of AB as shown in the figure. Draw the boundary of the prism with a sharp pencil.

6. Fix two alpins P_1 and Q_1 with sharp tips vertically about 10 cm apart, on the incident ray line $P_1 Q_1$ such that pin Q_1 is close to point O_1 . Close one eye (say left) and looking through the prism, bring your right eye in line with the images of the pins P_1 and Q_1 . Fix alpins R_1 and S_1 about 10 cm apart vertically on the white paper sheet with their tips in line with the tips of the images of pins P_1 and Q_1 . In this way pins R_1 and S_1 will become collinear, with the images of pins P_1 and Q_1 .
7. Remove the pins R_1 and S_1 and encircle their pin pricks on the white paper sheet with the help of a sharp pencil. Remove the pins P_1 and Q_1 and encircle their pin pricks also.
8. Join the points (or pin pricks) R_1 and S_1 with the help of a sharp pencil and scale, to obtain the emergent ray $R_1 S_1$. Produce it backwards to meet the incident ray $P_1 Q_1$ (produced forward) at T_1 . Draw arrowheads on $P_1 Q_1$ and $R_1 S_1$ to show the direction of the rays.
9. Measure the angle of deviation δ_1 and the angle BAC (angle A) of the prism (Fig. E 13.1) with a protractor and write the values of these angles indicated in the diagram.
10. Repeat steps 5 to 9 for different values of angle of incidence (40° , 45° , 50° ...) and measure the corresponding angles of deviation δ_2 , δ_3 ... with the protractor, and indicate them in the respective diagrams.
11. Record observations in tabular form with proper units and significant figures.

OBSERVATIONS

Least count of the protractor = ...(degree)

Angle of the prism, $A = \dots$ (degree)

Table E 13.1: Measuring the angle of incidence, i and angle of deviation δ for a prism

Sl. No.	Angle of incidence, i (degrees)	Angle of deviation, δ (degrees)
1		
2		
3		
--		
10		

Plotting the graph between i and δ for the prism

Take angle of incidence i along x-axis and angle of deviation δ along y-axis, using the observed values from Table E 13.1. Choose suitable scales on these axes and plot a graph between i and δ . Take care that you draw a free hand smooth curve passing practically through all the plotted points on the graph (Fig. E 13.3).

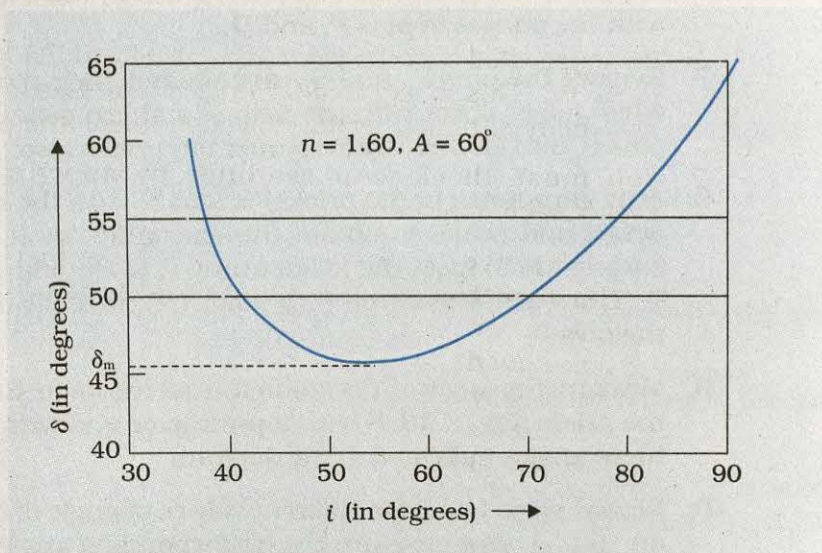


Fig. E 13.3 Graph between angle of incidence and angle of deviation

CALCULATIONS

Draw tangent on the lowest point of the graph parallel to x-axis, read the angle of minimum deviation δ_m on the y-axis of the graph. Express the result with proper significant figures.

RESULT

Angle of minimum deviation, $\delta_m = \dots \pm \dots$ degree

PRECAUTIONS

1. Alpins should be fixed vertically to the plane of paper.
2. Distance PQ and RS should be about 10 cm in order to locate incident and emergent rays with greater accuracy.
3. Same angle of prism should be used for all observations.
4. Position of the prism should not be disturbed for a given set of observations.

SOURCES OF ERROR

1. If the three angles of refraction between adjacent pairs of faces are not equal, then $A + \delta \neq i + e$.
2. There may be an error in measuring the values of the angles.

DISCUSSION

1. It is suggested that the value of angle of incidence be taken more than 35° . This is required for angles less than 35° as there is a possibility of total internal reflection inside the prism.
2. You must check your readings by applying the formula $i + e = A + \delta$.
3. The $i - \delta$ curve that is obtained in this experiment is a non-linear curve. In such situations, more readings should be taken in the minimum deviation region to be able to obtain the value of angle of minimum deviation accurately. For example, if δ readings are taken initially at 35° , 40° , 45° and 50° and if the $i - \delta$ data points are situated as shown in Fig. E 13.3 then a few more readings need to be taken for values of i in the range 45° to 55° say, at a difference of 1° or 2° .

Taking more readings in this region will help in drawing a smooth curve. This will enable you to locate the position of the lowest point on the graph more accurately.

4. In the condition of minimum deviation, the refracted ray inside the prism becomes parallel to its base so as to satisfy the condition $r = r'$.
5. The graph does not show a sharp minimum. We have same deviation for a range of angle of incidence near minimum deviation. Therefore extra care should be taken in drawing tangential line to the $i - \delta$ graph at minimum deviation.

SELF ASSESSMENT

1. Interpret the graph between i and δ .
2. If the experiment is performed with angle of emergence taken as angle of incidence, will there be any change in the δ values? If yes, why? If not, why not?
3. What will happen if you go on decreasing the angle of incidence? If you think there is a minimum, try to find its expression theoretically. What happens when i is less than the minimum angle of incidence?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Use the following equation to calculate refractive index of the material of the prism from the measured value of the angle A and δ_m determined from the graph.

$$n = \frac{\sin i}{\sin r} = \frac{\sin [(A + \delta_m)/2]}{\sin (A/2)}$$

2. Measure the angle of emergence e corresponding to the value of each angle of incidence i and angle of deviation δ you have observed. Compute the values of $(i + e)$ and $(A + \delta)$ and see how they compare.

3. Draw parallel horizontal lines cutting the $i - \delta$ curve, you have drawn, at various values of i and e . Find out the mid points of these horizontal lines and join these mid points. What is the shape of the curve so obtained? If you find that this shape resembles that of a straight line, find its (i) slope (ii) y-intercept and (iii) x-intercept.

4. Determine the refractive index of different liquids using a hollow prism by plotting $i - \delta$ graph.

5. Measure r and r' and e from the figures you have drawn. Find the refractive index of the material of the prism from the values of i and r and e and r' .

EXPERIMENT 14

AIM

To determine refractive index of a glass slab using a travelling microscope.

APPARATUS AND MATERIAL REQUIRED

A travelling microscope, a glass slab, lycopodium powder/chalk dust and a paper.

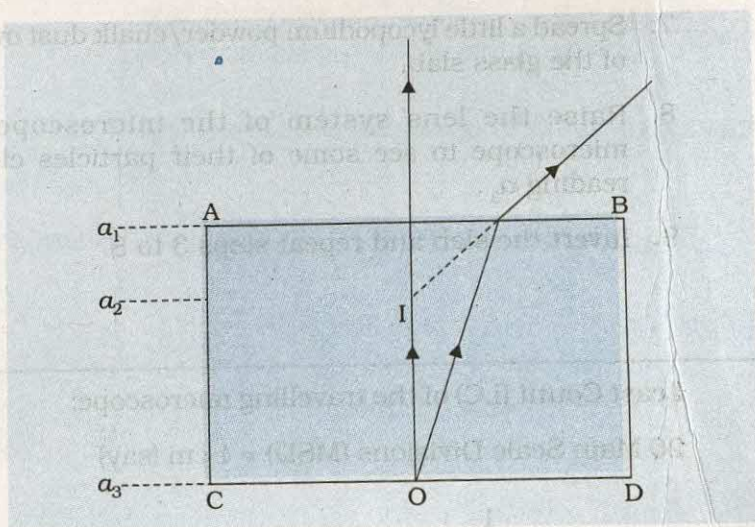


Fig. E 14.1 Formation of image I of a point O in a glass slab

PRINCIPLE

If a glass slab is placed in air on a horizontal surface and its bottom surface is viewed from top, it appears to be elevated due to the phenomenon of refraction. The distance between this apparent bottom and the top surface of the slab gives the apparent thickness of the slab. In case of normal observation, it can be shown that the refractive index of glass with respect to the medium, air is,

$$n_{ga} = \frac{\text{real thickness of the slab}}{\text{apparent thickness of the slab}}$$

PROCEDURE

1. Find the least count of the microscope scale, being used.
2. Put a mark on a sheet of paper.
3. Place the paper on the horizontal platform of the microscope. Adjust the microscope in such a way that its lens system is vertically above the mark.
4. Focus the microscope on the mark and record the reading a_1 using Main Scale Reading (MSR) and Vernier Scale Reading (VSR) of its coinciding division as shown in the Table E 14.1.
5. Next, place the glass slab over the mark on the sheet of paper.
6. Move the microscope upward until mark on the paper, seen through the slab is sharp and clear. Take the reading a_2 with the main scale and coinciding division of the vernier scale.
7. Spread a little lycopodium powder/chalk dust over the top surface of the glass slab.
8. Raise the lens system of the microscope and focus the microscope to see some of their particles clearly and record reading a_3 .
9. Invert the slab and repeat steps 3 to 8.

OBSERVATIONS

Least Count (LC) of the travelling microscope:

20 Main Scale Divisions (MSD) = 1 cm (say)

$$\therefore 1 \text{ MSD} = \frac{1}{20} \text{ cm}$$

50 Vernier Scale Divisions (VSD) = 49 MSD (say)

$$\therefore 1 \text{ VSD} = \frac{49}{50} \text{ MSD} = \frac{49}{50} \times \frac{1}{20} \text{ cm}$$

Least Count of the microscope = (1 MSD - 1 VSD)

$$= \left[\frac{1}{20} - \left(\frac{49}{50} \right) \times \frac{1}{20} \right] = \frac{1}{20} \left(1 - \frac{49}{50} \right) \text{ cm}$$

$$\text{LC} = 0.001 \text{ cm}$$

Table E 14.1: Refractive index of glass slab

Sl. no.	Reading of the microscope when focused on								
	Mark made on paper			Mark on paper through the slab			Particles on top of the glass surface		
	M.S.R. M (cm)	V.S.R. N (cm)	$a_1 = M + N \times$ L.C. (cm)	M.S.R. M (cm)	V.S.R. N (cm)	$a_2 = M + N \times$ L.C. (cm)	M.S.R. M (cm)	V.S.R. N (cm)	$a_3 = M + N \times$ L.C. (cm)
1									
2									
3									

CALCULATIONS

The refractive index n_{ga} is given by

$$n_{ga} = \frac{\text{real thickness of the slab}}{\text{apparent thickness of the slab}} = \frac{a_1 - a_3}{a_1 - a_2} = \frac{b}{c} \text{ (say)}$$

Find n_{ga} for the two sets of observations and then the mean value of n_{ga} .

Error

The estimated uncertainty in the measurement of n_{ga} is

$$\frac{\Delta n_{ga}}{n_{ga}} = \left(\frac{\Delta b}{b} + \frac{\Delta c}{c} \right) \quad \text{(E 14.1)}$$

$$\text{where } \frac{\Delta b}{b} = \left(\frac{\Delta a_1}{a_1} + \frac{\Delta a_3}{a_3} \right) \quad \text{(E 14.2)}$$

$$\text{and } \frac{\Delta c}{c} = \left[\frac{\Delta a_1}{a_1} + \frac{\Delta a_2}{a_2} \right] \quad \text{(E 14.3)}$$

From Eq. (E14.1)

$$\frac{\Delta n_{ga}}{n_{ga}} = \left(\frac{2\Delta a}{b} + \frac{2\Delta a}{c} \right)$$

$$\text{or } \Delta n_{ga} = 2n_{ga} \left[\frac{\Delta a}{b} + \frac{\Delta a}{c} \right]$$

Δa = least count of microscope and hence uncertainty in a_1 , a_2 , and a_3 measurements.

Maximum value of Δn_{ga} as obtained from the two sets of observations should be reported with the result as experimental error.

RESULT

The refractive index of glass of the slab was found to be $n_{ga} \pm \Delta n_{ga} = \dots \pm \dots$

n_{ga} is mean value of refractive index of glass with respect to the medium air.

PRECAUTIONS

1. The screws used in focussing the microscope should be moved in only one direction to avoid *back-lash error*.
2. Once the microscope is focused for the first reading i.e., a_1 , the focusing arrangement in the lens system should not be changed/alterd for subsequent readings namely for a_2 and a_3 .
3. The glass slab should be placed on a horizontal surface.
4. Use hand lens/magnifying glass to read the vernier scale to avoid error in finding vernier coinciding division.

SOURCES OF ERROR

1. Position of the microscope may not be normal to the surface of the glass slab.
2. If the layer of lycopodium powder/chalk dust spread on the glass slab is thick, it will not actually represent the top of the glass slab and thus produce error in the result.

DISCUSSION

1. You will get a feel of the apparent and real depths if you try to lift a coin in a bucket filled with water.
2. Consider the situation in which rays coming from an object strike on the glass slab obliquely. Can you obtain a mathematical expression for n_{ga} ?

SELF ASSESSMENT

1. Will a colourless slab be visible if immersed in a transparent liquid of the same refractive index as that of the slab? State the reason for it.

2. You have three slabs of same dimensions – the first one being hollow and completely filled with water, the second one is made of crown glass and the third flint glass. If each of them has a coloured mark at the bottom, in which case will it appear to have risen the most?

Given its $n_{\text{flint}} > n_{\text{crown}} > n_{\text{water}}$

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

Use the method mentioned above to find the refractive indices of commonly available transparent liquids. You may use a thin glass beaker for this experiment.

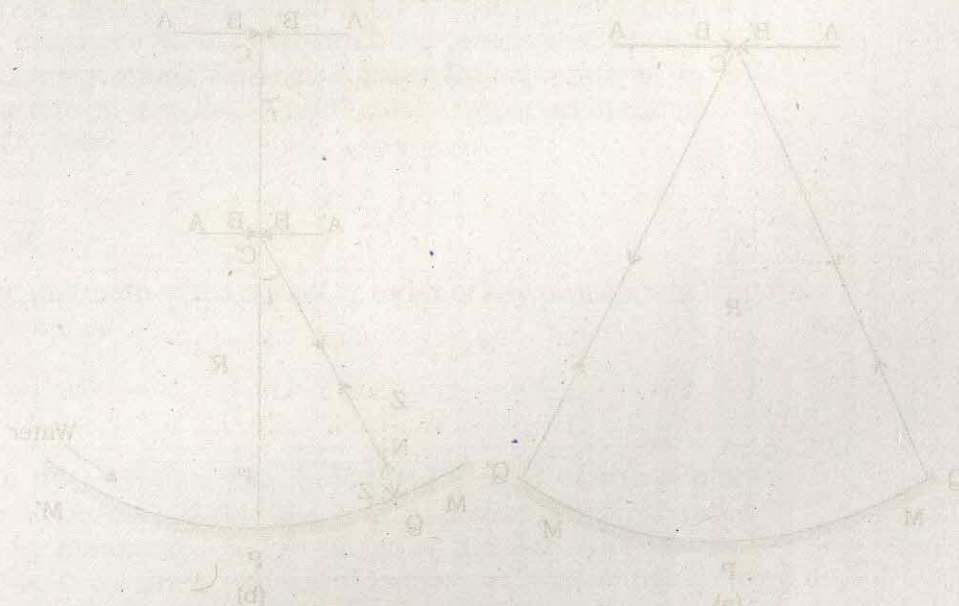


Fig. E.16.1 Formation of image AB of an object AB by a concave mirror M. placed at its centre of curvature (a) Mirror without water, and (b) Mirror with some water.

EXPERIMENT 15

AIM

To determine the refractive index of a liquid (water) using (i) concave mirror, (ii) convex lens and a plane mirror.

(i) Refractive index of water using concave mirror

APPARATUS AND MATERIAL REQUIRED

Concave mirror of small aperture and large focal length, water, a laboratory stand with rigid base and clamp arrangement (height of the stand must be more than double the focal length of the given concave mirror), a pin, a metre scale, a spirit level, a plumb line, and some small cork pieces.

PRINCIPLE

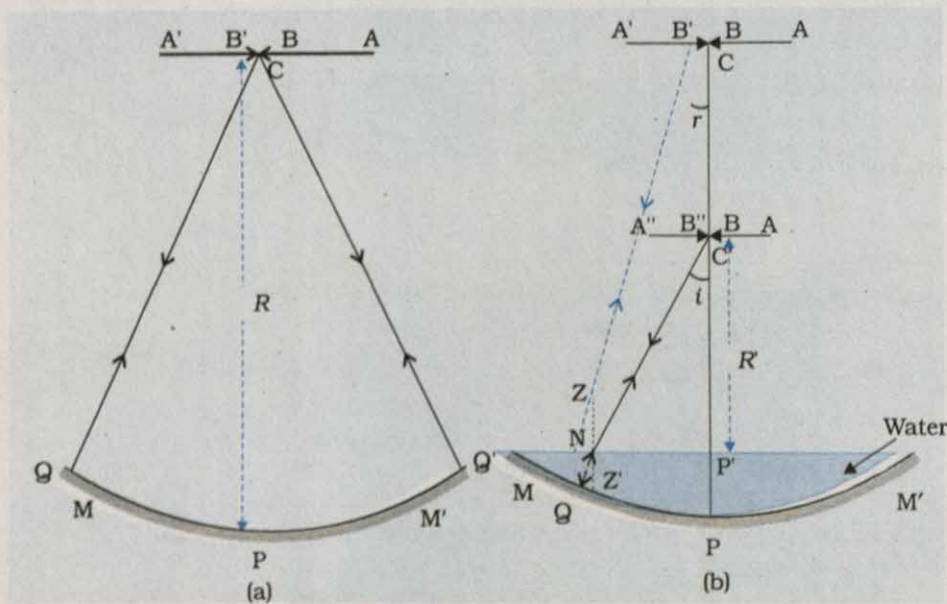


Fig. E 15.1 Formation of image $A'B'$ of an object AB by a concave mirror MM' placed at its centre of curvature. (a) Mirror without water and (b) Mirror with some water

When an object is placed in front of the reflecting surface of a concave mirror MM' at a distance equal to its radius of curvature R , a real and inverted image is formed at the centre of curvature, i.e., $u = v = R = \text{distance } PC$; P being the pole of the mirror [Fig. E15.1 (a)]. Thus the centre of curvature C of a concave mirror can be located by the method of parallax between

a sharp-edged pin and its real and inverted image formed by a concave mirror.

Fig. E 15.1(b) shows the location of centre of curvature C' when the mirror is partially filled with some transparent liquid (say water). In this case the parallax between the object pin and image of the pin would be removed at a shorter distance from the pole P of the mirror. The incident ray $C'N$ is refracted at the water-air boundary along the path NM such that it falls normally on the curved reflecting surface at point M . The reflected ray retraces back on the same path along MN in water and meets the axis at C along NC , when produced. In air, actually the reflected ray travels along NC' . Thus the real and inverted image is formed at C' . Therefore the distance PC' would be the apparent radius of curvature R' of the water-filled concave mirror.

Fig. E 15.1(b) shows the refraction of incident ray $C'N$ in water. Let ZZ' be the normal at the water surface. $\angle ZNC'$ and $\angle ZNC$ are the angles of incidence i and refraction r , respectively. From geometrical arguments, it is clear that $\angle i = \angle NC'P$ and $\angle r = \angle NCP$. Thus, the refractive index of water with respect to air n_{wa} can be given as:

$$n_{wa} = \frac{\sin i}{\sin r} = \frac{NP'/NC'}{NP/NC} = \frac{NC}{NC'}$$

For a mirror having very small aperture and large radius of curvature, distances NC and NC' can be approximated as distances PC and $P'C'$, respectively. Further, if only a little quantity of water is taken in the mirror, then distance PP' can be neglected in comparison to PC or PC' . Thus

$$n_{wa} = \frac{PC}{PC'} = \frac{R}{R'}$$

Thus, using this method the refractive index of any transparent liquid can be determined.

PROCEDURE

1. Obtain approximate value of focal length of the concave mirror by focussing the image of a distant object. It can be found by obtaining a sharp image of the Sun or a tree on a plane wall or on a sheet of paper, and measuring the distance between the mirror and image with a scale. This distance is an approximate value of the focal length f , of the concave mirror. Twice of this focal length is an approximate value of the radius of curvature of the mirror.

Note: Do not look at the Sun's image in a concave mirror as it may hurt your eyes.

2. Place the given concave mirror on the base of a firm and stable laboratory stand keeping its reflecting surface upwards. Use a spirit level to ensure that the plane on which the mirror rests is horizontal. It makes the principal axis of the mirror vertical. Some pieces of paper, plasticine or cork may be used to keep the position of mirror stable on the stand.
3. Fix a sharp edged bright pin in the clamp and place it horizontally just above the mirror. Adjust the position of the pin such that its tip B lies just above the pole P of the mirror or lies on the principal axis of the mirror.
4. Shift the clamped pin to a distance roughly equal to twice the rough focal length of the concave mirror (obtained in step 1) from the pole P of the mirror placed on the laboratory stand. Once again verify that the tip of the pin and pole P lie along the same vertical line (principal axis of the mirror).
5. Adjust the position of the pin till the parallax between the tip of the pin and its inverted image is removed.
6. Measure the vertical distance between the tip of the pin and the mirror using a plumb line and metre scale. This distance would be the real radius of curvature of the mirror.
7. Pour some water on the curved surface of the mirror.
8. Lower the pin slowly, till once again the parallax between the tip of the pin and its inverted image formed by the water-filled mirror is removed.
9. Remove water from the mirror and measure the vertical distance between the tip of the pin and the mirror. This distance would be the apparent radius of curvature of the water-filled mirror.
10. Repeat the experiment (steps 2 to 9) atleast two more times.

OBSERVATIONS

1. Approximate value of the focal length of the concave mirror, $f = \dots$ cm.
2. Approximate value of the radius of curvature, $R = 2f = \dots$ cm.

Table E 15.1: Observations for R , R' and n_{wa}

Sl. No.	Position of pin with respect to pole P		$n_{wa} = \frac{R}{R'}$	Δn_{wa}
	For empty concave mirror, distance PC R (cm)	For water - filled mirror, distance PC' R' (cm)		
1				
2				
3				
Mean				

CALCULATIONS

Calculate n_{wa} and its mean value.

Error

$$\frac{\Delta n_{wa}}{n_{wa}} = \frac{\Delta R}{R} + \frac{\Delta R'}{R'}$$

$$\therefore \Delta n_{wa} = \left[\frac{\Delta R}{R} + \frac{\Delta R'}{R'} \right] n_{wa}$$

RESULT

The refractive index of water with respect to air is $n_{wa} \pm \Delta n_{wa} = \dots \pm \dots$

n_{wa} is mean value and Δn_{wa} is the maximum of the three values of error.

PRECAUTIONS

1. Pin should be kept horizontal and above the curved reflecting surface of the horizontally placed concave mirror such that the tip of the pin lies above the pole of the mirror on its vertical principal axis.
2. Aperture of mirror should be small.
3. The mirror should be very thin otherwise multiple reflections will form an unclear image.
4. The quantity of water taken in the mirror should be sufficient so that the water surface remains horizontal, or else the surface may not remain horizontal because of surface tension.
5. Eye should be kept at a distance of more than 25 cm from the pin.

SOURCES OF ERROR

The line joining PC may not be vertical.

DISCUSSION

1. If the refractive index of water is determined using concave mirrors of different radii of curvature, how will this affect the values of the refractive index?
2. A plumb line may be used to find the accurate value of PC and PC'. How can plumb line ensure correct measurement?

SELF ASSESSMENT

1. Find the refractive index of water from this experiment considering that a concave mirror filled with water behaves as a combination of concave mirror and a plano-convex lens.
2. If you gradually increase the quantity of water in the mirror, starting with a few drops, do you expect any change in the position or brightness of the image?
3. If colours are added to water keeping its transparency, would this alter the value of refractive index and intensity of the image?
4. If a small quantity of some transparent liquid (like kerosene) lighter than water is added such that it forms a thin film on the water surface; can the experiment still be performed? If so, would the value of refractive index change?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Determine the refractive indices of different liquids (white vinegar, kerosene, glycerine, cooking oil).
2. Take a table lamp. Covering it with cellophane paper of various colours, determine the refractive index of a liquid (say, water) using a concave mirror. Do you observe any change in the value of refractive index of the liquid?
3. Study the variation in the refractive index of salt/sugar solution by changing its concentration.

(ii) Refractive index of water using convex lens and a plane mirror

APPARATUS AND MATERIAL REQUIRED

Double convex lens (focal length nearly 20 cm), plane mirror (bigger in size than the aperture of the lens), laboratory stand fixed with a pin in clamp, metre scale, plumb line, water dropper.

PRINCIPLE

In this method, a real and inverted image coincides with the object placed on the principal focus point of a convex lens. The rays from a pin AB placed on the principal focus F of a convex lens emerges out parallel to its axis. When these rays fall normally on a plane mirror placed horizontally below the convex lens, they retrace their path and form a real and inverted image $A'B'$ at the principal focal plane of the lens [Fig. E 15.2(a)]. The size of image $A'B'$ is equal to the size of object pin AB and the tip of the pin gives the position of the second principal focus. Then $f(OF)$ is the focal length of the convex lens (for a thin lens) where O is the optical centre of the lens.

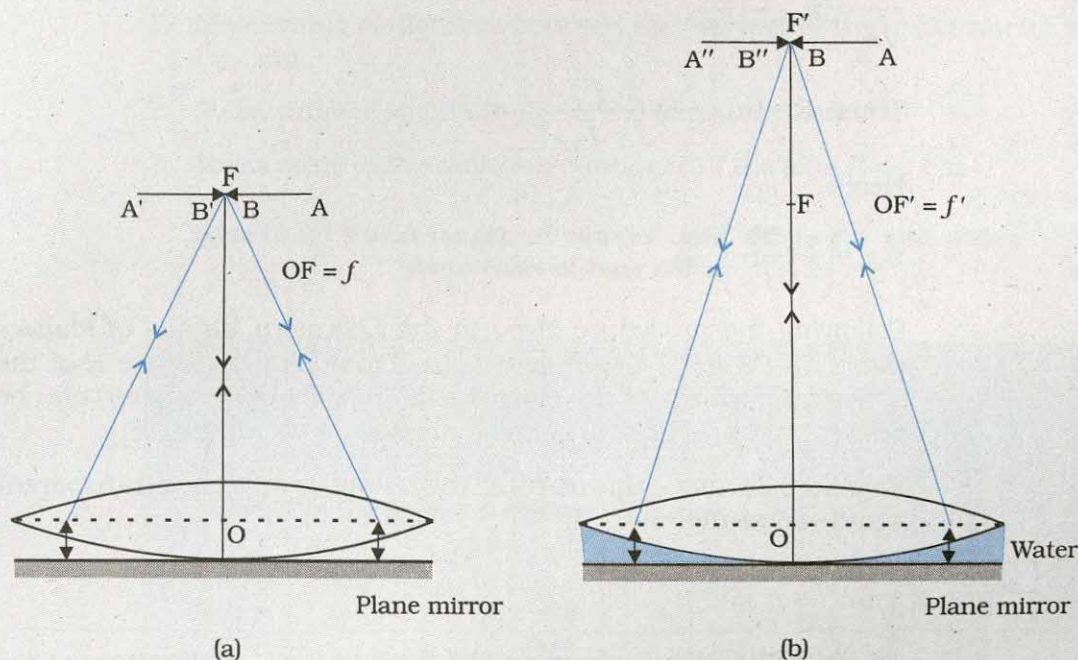


Fig. E 15.2 Image formed by a equiconvex lens backed by a plane mirror coinciding with the object AB. (a) $A'B'$ when there is air in between the lens and the mirror; and (b) $A'B'$ when there is water in between the lens and mirror

Now, if the space between the lens and the plane mirror is filled with a transparent liquid (say water) having refractive index n_{wa} , and the above procedure is repeated to find the position of the principal focus F in the new situation then the distance between the optical centre O

of the lens and point F' , OF' (say f') would be the focal length of the combination of the two lenses. The combination consists of a glass convex lens (radius of curvature of both the curved surfaces are same, R) and a water plano-concave lens of same radius of curvature, R . The focal length f_w of water lens can be determined from the relation between the three focal lengths. viz. f , f' , and f_w , i.e.,

(E 15.1)

$$\frac{1}{f'} = \frac{1}{f} + \frac{1}{f_w}$$

(E 15.2)

$$\frac{1}{f_w} = \frac{f - f'}{f f'}$$

But with sign convention : $f = +ve$, $f' = +ve$ one finds $f_w = -ve$

$$f_w = \frac{f f'}{f - f'}$$

Also, from the lens maker's formula for a plano-concave lens

(E 15.3)

$$\frac{1}{f_w} = (n_{wa} - 1) \frac{1}{R}$$

$$\text{Thus, } R = (n_{wa} - 1) \frac{f f'}{f - f'}$$

Hence,

(E 15.4)

$$n_{wa} = \left(1 + \frac{R}{f_w} \right)$$

Following the procedure given in the *Laboratory Manual of Physics Class XI, (NCERT) Experiment-3*, the radius of curvature R of the spherical surfaces of the convex lens (using a spherometer) can be determined, and Eq. 15.4 can be utilised for calculating n_{wa} .

Therefore, by using this method, the refractive index of a transparent liquid can be determined.

PROCEDURE

1. Place the plane mirror on the base of a rigid laboratory stand keeping its reflecting surface upwards.
2. Place the convex lens on the plane mirror.
3. Fix a sharp-edged bright pin in the clamp and place it horizontally and above the lens. Adjust the position of the pin such that its tip B lies vertically above the optical centre of the convex lens. A plumb line and a spirit level may be used to achieve this.

- Shift the clamped pin gradually upward looking at the image and bring it to a height such that the tip B of the pin exactly coincides with the tip of its image B'. Ensure that there is no parallax between the object pin and its image. Measure the distance OF [Fig. E 15.2(a)]. For this, observe the distances of the pin from the upper and lower surfaces of the lens and take $OF = f$ as the average of these two distances.
- With the help of a dropper, put a few drops of water under the lens so that the space between mirror and lens is filled with water.
- Move the object pin upward and remove the parallax between the tip of the object pin and its image formed by the lens mirror system. Measure the distance OF' [Fig. E 15.2(b)]. Here again, as before, measure the distances of the pin from the two surfaces of the lens and take $OF' = f'$ as their average.
- Repeat the experiment and record your observations in Table 15.2.

OBSERVATIONS

- Mean value of distance between the two legs of the spherometer $l = \dots \text{cm}$
- Mean value of sagitta (bulge of the lens) $h = \dots \text{cm}$
- Mean value of the radius of curvature of the lens $R = \dots \text{cm}$

Table 15.2 : Focal length of convex lens, OF (= f) and water plano-convex lens OF' (= f')

Sl. No.	Position of pin with respect to optical centre O			$f_w = \frac{f f'}{f - f'}$			Δf_w	n_{wa}	Δn_{wa}
	Without water ($OF = f$)			With water ($OF' = f'$)					
	Distance of the pin from			Distance of the pin from					
	Upper surface of the lens	Plane mirror	$\frac{d_1 + d_2}{2}$	Upper surface of the lens	Plane mirror	$\frac{d_3 + d_4}{2}$			
	d_1 (cm)	d_2 (cm)	f (cm)	d_3 (cm)	d_4 (cm)	f' (cm)			
1									
2									
3									
				Mean					

CALCULATIONS

$$n_{wa} = \left(1 + \frac{R}{f_w} \right)$$

Error

$$\frac{\Delta n_{wa}}{n_{wa}} = \frac{\Delta R}{R} + \frac{\Delta f_w}{f_w}$$

$$\text{or } \Delta n_{wa} = n_{wa} \left[\frac{\Delta R}{R} + \frac{\Delta f_w}{f_w} \right]$$

$$\text{where } \Delta R = R \left[\frac{2\Delta l}{l} + \frac{2\Delta h}{h} \right]^*$$

We use Eq. 15.1 for finding the value of Δf_w .

$$\frac{\Delta f_w}{f_w^2} = \frac{\Delta f}{f^2} + \frac{\Delta f'}{f'^2}$$

$$\text{or, } \Delta f_w = f_w^2 \left[\frac{\Delta f}{f^2} + \frac{\Delta f'}{f'^2} \right]$$

Note that Δl , Δh , Δf and $\Delta f'$ represent least count of the measuring scale.

RESULT

The refractive index of a given liquid (say water) with respect to air is $n_{wa} + \Delta n_{wa} = \dots \pm \dots$

Here, n_{wa} is mean value and Δn_{wa} is the maximum of three values of error.

PRECAUTIONS

1. Pin should be kept horizontal and its tip should be above the optical centre of the lens on its vertical principal axis otherwise it will be difficult to remove the parallax.
2. The thin lens should be used so that the distance measured from its surface is nearly equal to the distance measured from the

optical centre. Still it is better to measure distance from both the surfaces and take the average for f or f' .

3. Water should be gently put between the mirror and the lens surface with the help of a dropper so that it may fill up the air space between them without disturbing the position of the lens.

SOURCES OF ERROR

1. Two surfaces of the convex lens may not have the same radius of curvature.
2. The plane mirror may not be horizontal.

DISCUSSION

1. Convex lens used should be thin. How will the result change if a thick lens is used?
2. How is a plumb line effective in ensuring that the rays retrace their path after refraction through the lens and reflection from the mirror? Draw suitable diagram with principal axis at an angle to the vertical, showing the plane mirror at an angle to the horizontal.

SELF ASSESSMENT

1. What will happen if you are given a convex lens of small focal length?
2. What are the basic assumptions you have made in performing this experiment?
3. Why do we have to raise the object pin upward after filling water between the lens and the mirror?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Find out refractive index of any other transparent liquid using this method.
2. Study the effect of change in concentration of a solution taken in between the lens and mirror on the refractive index of the solution.
3. Measure the focal length of the given convex lens using a plane mirror. Now replace the plane mirror with a convex mirror of the same curvature, and repeat the experiment to find the focal length of the lens. Draw a suitable ray diagram.

EXPERIMENT 16

AIM

To draw the $I - V$ characteristic curves of a p-n junction in forward bias and reverse bias.

APPARATUS AND MATERIAL REQUIRED

A p-n junction diode (OA-79 or 1N4007), a resistor of value (3Ω , $1/2W$), one variable voltage power supply (0-12V), voltmeter (0-12V), milliammeter (0-200 mA), a plug key, connecting wires, sand paper and a microammeter (0-200 μA).

TERMS AND DEFINITIONS

1. *Forward bias*: When an external voltage is applied to a p-n junction diode in such a way that the p-side is at a higher potential with respect to the n-side, it is said to be forward biased.
2. *Threshold voltage or "Cut-in" voltage*: When the p-side is connected to the positive terminal of the battery and the voltage is increased, initially a negligible current flows till the applied voltage crosses a certain value. After, a characteristic voltage, the diode current increases significantly (exponentially), even for a very small increase in the diode bias voltage. This voltage is called the threshold voltage or cut-in-voltage of the diode.
3. *Reverse bias*: When the n-region of a p-n junction diode is at a higher potential with respect to the p-region, it is said to be reverse biased. In reverse bias, the p-side of the p-n junction diode is connected to the negative of the battery.
4. *Reverse saturation current*: As the applied voltage is increased in the reverse biased condition, starting from zero value, the current increases, but soon becomes constant. This current is very small (a few microamperes). It is called the reverse saturation current.

PROCEDURE

1. Note the range and least count of the given voltmeter (V), milliammeter (mA) and the microammeter (μA).
2. Remove the insulating layers from the connecting wires and leads of diode using a sand paper.
3. Connect the variable voltage power supply, p-n junction diode, voltmeter, milliammeter, resistor and a plug key in a circuit as shown in Fig. E 16.1.
4. Initially when the key is open, you would note at this stage, that no current is flowing through the circuit. Now close the key.
5. Give a small voltage to the circuit by slight and gentle turning of the power supply knob. Note the voltmeter reading across the diode and the corresponding milliammeter reading to find the current I flowing through the diode.
6. Gradually, increase the applied voltage (in steps) in the circuit and note the corresponding voltmeter and milliammeter readings in Table E 16.1.

The value of current flowing through the diode would be negligibly small till the voltage across the diode exceeds the value of its *cut-in or threshold voltage*. After the *cut-in voltage*, the variation in current will be rapid.

7. Once the threshold voltage is reached, vary the diode voltage very slowly (preferably in steps of 0.1V) noting the corresponding current I flowing through the diode. Continue increasing voltage till the current reaches the limit of the milliammeter.
8. Now disconnect the circuit and make the connections as shown in Fig. E 16.2 for the reverse bias characteristics. Connect p-side of p-n junction diode to the

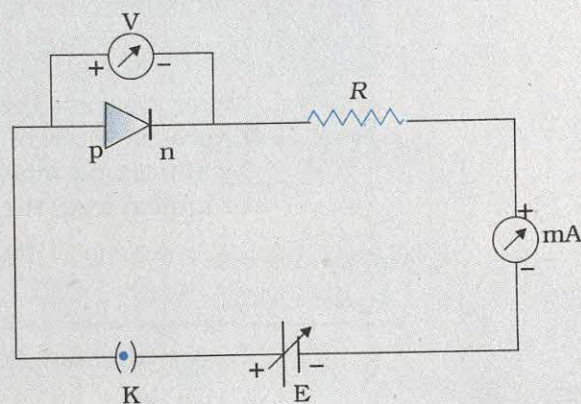


Fig. E 16.1 Forward biasing for a p-n junction diode

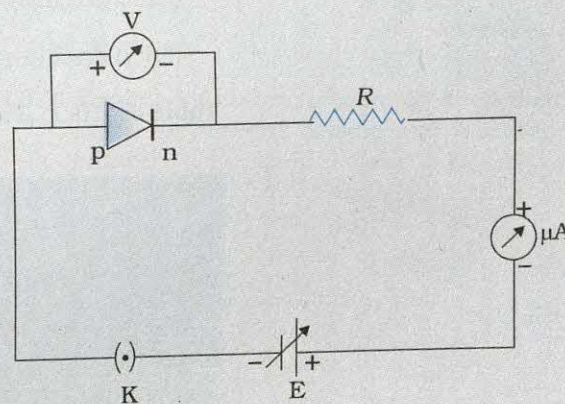


Fig. E 16.2 Reverse biasing for a p-n junction diode

negative terminal of the power supply and replace milliammeter with a microammeter. Gradually, increase the applied voltage (in steps) in the circuit and note the corresponding voltmeter and microammeter readings in Table E 16.2. In this part of experiment, with the given supply voltage you will get only flat portion of the reverse bias characteristic curve.

CAUTION

Never increase the value of the voltage too much across the diode. Excessive current flow may damage the diode if it exceeds its limit. Maximum permissible current that can pass through the diode can be known from the technical data as specified by the manufacturer.

OBSERVATIONS

1. p-n junction diode used (diode no.) = ...
2. For forward biasing
 - (i) Range of the voltmeter = ... V to ... V
 - (ii) Least count of the voltmeter scale = ... V
 - (iii) Range of the milliammeter = ... mA to ... mA
 - (iv) Least count of the milliammeter scale = ... mA
3. For reverse biasing
 - (i) Range of the voltmeter = ... V to ... V
 - (ii) Least count of the voltmeter scale = ... V
 - (iii) Range of the microammeter = ... μ A to ... μ A
 - (iv) Least count the microammeter = ... μ A

Table E 16.1: Variation of forward current with voltage across the diode (forward bias)

Sl.No.	Forward voltage V_f (V)	Forward current I_f (mA)
1		
2		
3		
-		
20		

Table E 16.2: Variation of reverse current with voltage across the diode (reverse bias)

Sl.No.	Reverse voltage V_r (V)	Reverse current I_r (μ A)
1		
2		
...		
20		

PLOTTING GRAPH

1. Plot a graph between forward voltage across the diode (V_f) along the positive x-axis and current flowing through the diode (I) along the positive y-axis. The graph as shown in Fig. E 16.3 represents a typical I - V characteristic of a silicon diode used. Locate the knee and determine the cut-in voltage.
2. Now plot the reverse voltage (V_r) along the negative x-axis and the corresponding current (in μ A) along the negative y-axis as shown in Fig. E 16.3. Determine the reverse saturation current.

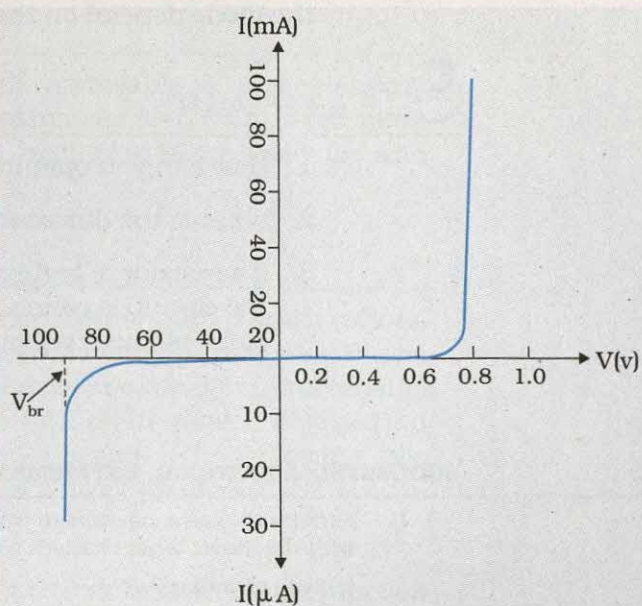


Fig. E 16.3 Typical I - V characteristics of a silicon diode in forward biasing and reverse biasing

RESULT

- A. The value of cut-in voltage for the given diode is ... V.
- B. The reverse saturation current for the given diode is... μ A.

PRECAUTIONS

1. Find out manufacturer's specification for maximum permissible

current through the given diode in forward bias. Take care not to exceed this limit.

2. Find out manufacturers specification for maximum reverse voltage to be applied to the diode. Take care not to exceed this limit.
3. It is important to take care that the potential difference across the diode is increased gradually, in small steps. Keep your eyes on the ammeter and let the current not exceed the specified limit.

DISCUSSION

If we use different diodes (Ge or Si), what change do you observe in the I - V characteristics? Does the threshold voltage / cut-in voltage of the diode depend on the material of the diode?

SELF ASSESSMENT

1. How can you operate diode as a switch or as a rectifier?
2. What is the difference between a diode and a resistor?
3. If a resistor of higher value (greater than the resistor connected in the circuit) is connected in series with diode, then comment on the slope of linear region of I - V characteristics.

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Perform the same experiment with a different value of R connected in series with the diode. What changes will be observed in
 - (a) cut-in voltage?
 - (b) actual value of current for same voltage for different values of R ?
 - (c) shape of I - V characteristics?
2. Perform the same experiment with a light emitting diode (LED) in place of a diode and plot the I - V characteristics. What change do you observe in the threshold voltage when you use different coloured LEDs?

EXPERIMENT 17

AIM

To draw the characteristic curve of a Zener diode and to determine its reverse breakdown voltage.

APPARATUS AND MATERIAL REQUIRED

A p-n junction Zener diode (IN 758), a variable dc power supply (0-15 V) with least count 0.1 V, a microammeter (0-100 μ A), a voltmeter (0-15 V), a resistance of 125 Ω , a high resistance rheostat and connecting wires.

PRINCIPLE

Zener diodes are essentially p-n junction diodes (both p and n regions are more heavily doped as compared to rectifying p-n junction diode) operated in the breakdown region of the reverse voltage characteristic. These diodes are designated with sufficient power dissipation capacities to work in the breakdown region. The following two mechanisms can cause breakdown in a junction diode:

(i) Avalanche breakdown

With increasing reverse bias voltage, the electric field across the junction of p-n diode increases. At a certain reverse bias, the electric field imparts a sufficiently high energy to a thermally generated carrier crossing the junction. This carrier, on colliding with a crystal ion on its way, disrupts a covalent bond and produces an electron-hole pair. These carriers on gaining sufficient energy from the applied field collide with other crystal ions and generate further electron-hole pairs. This process is cumulative and produces an avalanche of carriers in a very short time. This mechanism is known as avalanche multiplication, causes large reverse current and the diode is said to work in the region of avalanche breakdown.

(ii) Zener breakdown

In a Zener diode, both the p and n-sides are heavily doped. Due to the high dopant densities, the depletion layer junction width is small. Since the junction width is small i.e. less than 10^{-7} m, even a small

voltage across it may create a very high field. This high junction field may strip an electron from the valence band which can tunnel to the n-side through the thin depletion layer. Such a mechanism of emission of electrons after applying certain electric field ($\sim 10^6$ V/m) or voltage

V_z is termed as internal field emission which gives rise to a high reverse current or breakdown voltage. This breakdown is termed as *Zener breakdown* and the voltage at which it occurs is called *Zener voltage*. The reverse current at Zener voltage is called *Zener current*.

The very nature of breakdown suggests that the ideal V versus I characteristics (schematically as shown in Fig. E 17.1) of a Zener diode after breakdown will be running parallel to the current axis implying thereby, that a small change in voltage leads to almost infinite or very large change in current. You will appreciate that this is what we have called "breakdown" earlier. However, there is a danger of such a large current flow through the diode that it can result in its excessive heating. To protect the diode from such a damage, normally in practical circuits, we connect a resistance termed as protective resistance (R_p) with the Zener diode which limits the maximum current which can ever pass through the diode.

A simple method of determining the approximate value of protective resistance in practical circuits is discussed below:

Suppose we are given a Zener diode IN 758 with $V_z = 10$ V. This diode can withstand a maximum power dissipation of 0.4 W (as per the ratings given by the manufacturer). We can find a simple relation between protective resistance R_p and Zener breakdown voltage.

A Zener diode having zener voltage V_z and power dissipation rating P_z is connected

across a potential divider arrangement with maximum potential V_z across it (Fig. E 17.2). If the potential drop across the Zener diode is V_z and the rest drops across the protective resistance then we get

$$V = V_z + I_z R_p$$

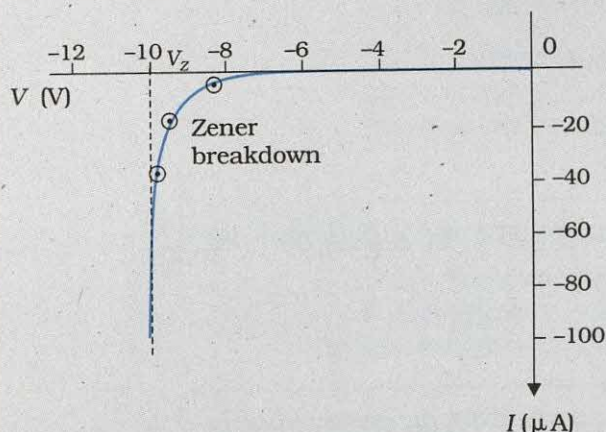


Fig. E 17.1 Zener diode characteristics curve

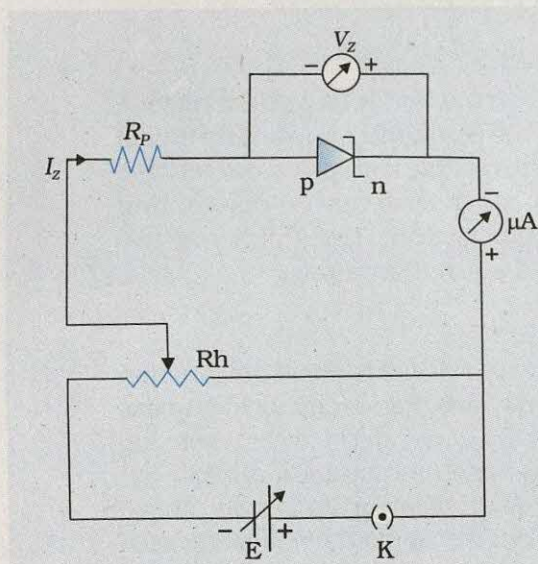


Fig. E 17.2 Circuit for Zener diode characteristic curve

Since
$$I_z = \frac{P_z}{V_z} \quad (\text{E 17.1})$$

$$V = V_z + \left(\frac{P_z}{V_z} \right) R_p$$

and
$$R_p = \frac{(V - V_z)V_z}{P_z} \quad (\text{E 17.2})$$

Therefore a resistance of value $R_p = \frac{(15 - 10)10}{0.4} = 125 \, \Omega$ should be connected in series with the Zener diode IN 758 to protect it from damage.

PROCEDURE

1. Note the least count of the given voltmeter and microammeter.
2. The voltmeter and microammeter should read zero with zero applied voltage. If not, then correct the initial reading of the meter suitably.
3. Clean the ends of the connecting wires with the help of sand paper and connect various components by the connecting wires as per the circuit arrangement (Fig. E 17.2). Take care that Zener diode is in reverse bias mode and the terminal of the microammeter and voltmeter marked positive are connected to the higher potential side of the power supply.
4. Ensure that the microammeter is connected in series with the Zener diode having a series protective resistance R_p and voltmeter in parallel to the Zener diode.
5. Switch on the power supply.
6. Move the contact point of the potential divider to apply some reverse bias voltage (V_r). For low reverse bias, the current is negligibly small i.e., of the order of 10^{-8} A to 10^{-10} A and hence with milliammeter or microammeter, you will observe zero reading.
7. Slowly increase the voltage across the Zener diode in steps and record the value of reverse bias voltage V_r and also record the corresponding reverse current I_r from the reading of the microammeter. Take care that the reverse voltage V_r is increased in steps of 0.1 V.

OBSERVATIONS

1. Range of the voltmeter = ... V to ...V
2. Least count of the voltmeter = ...V
3. Range of the microammeter = ... μ A to ... μ A
4. Least count of the microammeter = ... μ A
5. Specification of Zener diode used (code no.) = ...
6. To calculate the value of protective resistance R_p , following data is required.

Maximum permissible power (power rating) of the Zener diode specified by the manufacturer, $P_z = \dots$ W

Maximum permissible voltage (voltage rating) of the Zener diode as specified by the manufacturer, $V_z = \dots$ V

Value of the protective resistor to be used in series with the Zener diode, $R_p = \dots$ V (from E 17.2)

7. Note down the reading of the voltmeter and microammeter in Table E 17.1.

Table E 17.1: Variation of reverse current I_r with reverse voltage, V_r across the Zener diode

Sl.No.	For Zener diode	
	Voltmeter reading V_r (V)	Microammeter I_r (μ A)
1		
2		
--		
10		

PLOTting GRAPH

- (i) Plot a graph between reverse voltage, V_r and reverse current, I_r taking V_r along x-axis and I_r along y-axis by using the readings from Table E 17.1.
- (ii) Discuss the nature of $V_r - I_r$ graph and interpret it.
- (iii) Note the value of the breakdown voltage from the $V_r - I_r$ graph.

RESULT

The breakdown voltage of the Zener diode obtained from the graph is

$$V_z = \dots \text{ V.}$$

PRECAUTIONS

1. Ends of the connecting wires should be cleaned properly with sand paper.
2. Zero reading of voltmeter and microammeter should be checked properly.

DISCUSSION

1. Ideally after breakdown, the current I_r should become infinitely large. Is it so in your case? In case it is not and you find that the current does increase rapidly but not infinitely, then think of the reason. Does the protective resistance or any other contact resistance in the circuit has any role to play in this case?
2. From the manual of electric components, note down the breakdown voltages of the Zener diodes which can be used in any circuit for different voltages.
3. Discuss the role of Zener diode in voltage regulation.

SELF ASSESSMENT

1. What is the principle of Zener diode?
2. How is reverse current obtained?
3. What happens at Zener breakdown?
4. What is meant by internal field emission?
5. How can you use a Zener diode as a voltage regulator?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

Repeat the experiment using Zener diodes of different code numbers. Do you observe any variation in their reverse breakdown voltages?

EXPERIMENT 18

A_{IM}

To study the characteristics of a common emitter n-p-n (or p-n-p) transistor and to find out the values of current and voltage gains.

A_{PPARATUS AND MATERIAL REQUIRED}

A transistor (BC 147 or BC 177 or AC 128), a microammeter (0-100 μ A), a milliammeter (0-20 mA), two high resistance rheostats, a 100k Ω carbon resistance, two dc power supplies to provide voltage both for input (0-3V) and output (0-15V), two one way keys and connecting wires.

P_{RINCIPLE}

An n-p-n transistor is made up of a semiconductor such as Ge or Si in which there is a thin p-type layer between two n-type layers. A p-n-p transistor has a thin n-type layer between two p-type layers. The schematic diagram of n-p-n and p-n-p transistors along with their circuit symbols are shown in Fig. E 18.1(a) and E 18.1(b) respectively.

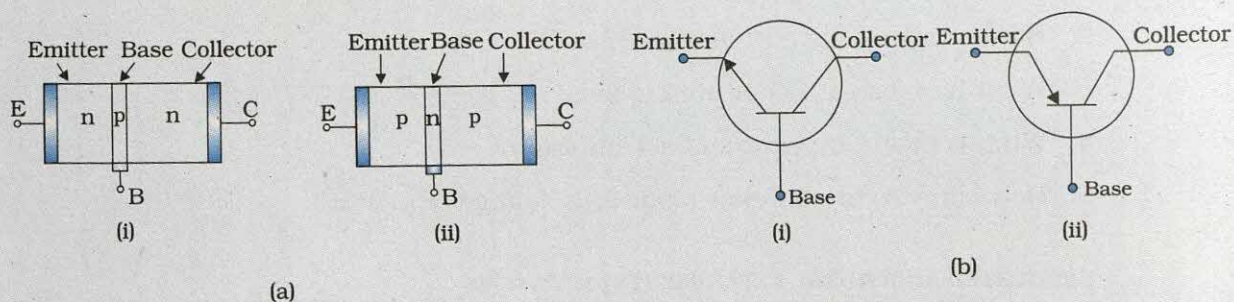


Fig. E 18.1 (a) Schematic representations of n-p-n and p-n-p transistors along with their (b) circuit symbols

The middle portion of the transistor is called base. It is very thin and lightly doped. Emitter is of moderate size and heavily doped. The collector is moderately doped and larger in size as compared with

emitter. When a transistor is to be connected in a circuit, one of the terminals has to be common between the input and output. Thus, three circuit configurations are possible.

- (i) common emitter (CE) configuration
- (ii) common base (CB) configuration
- (iii) common collector (CC) configuration.

CE configuration

When a transistor is used in CE configuration, the input is fed between the base-emitter terminals and the output is derived between the collector-emitter terminals as shown in Fig. E 18.2 (a) and (b).

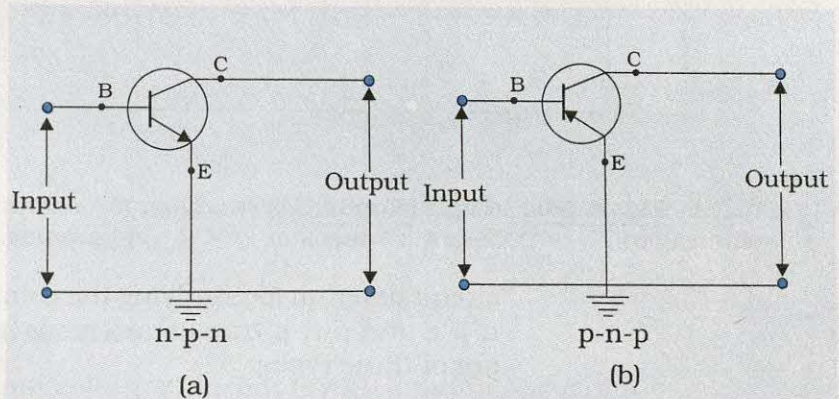
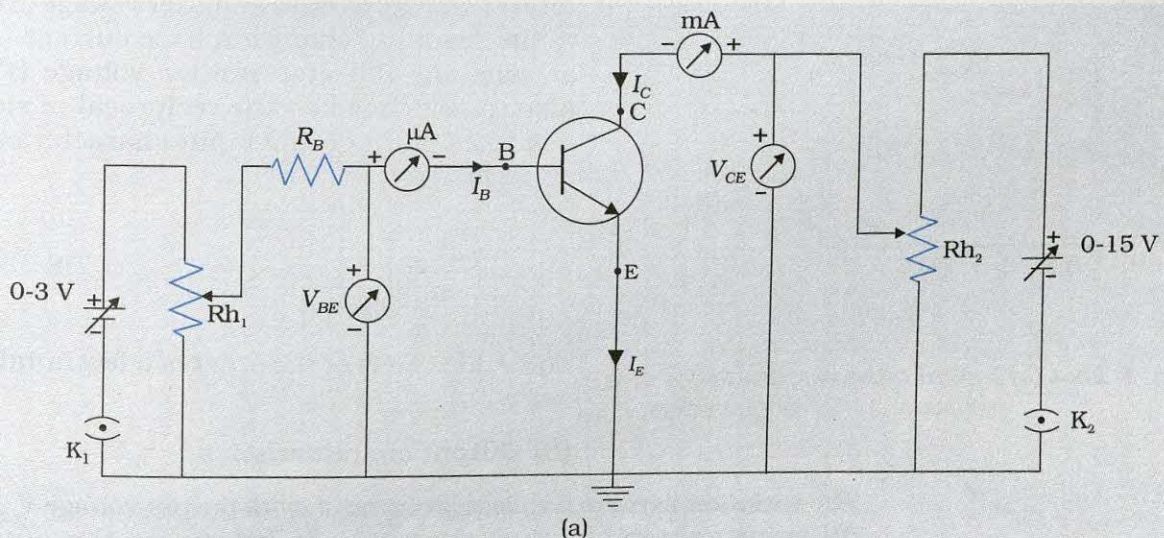


Fig. E 18.2 Input is fed between the base and emitter terminals and the output part is obtained between the collector and emitter terminals in CE configuration in (a) n-p-n transistor (b) p-n-p transistor

The characteristics of a transistor when the emitter is kept as a common terminal and grounded, the base as input terminal and the collector as output terminals, are called common emitter characteristics. Fig.E 18.3 (a) and (b) show the



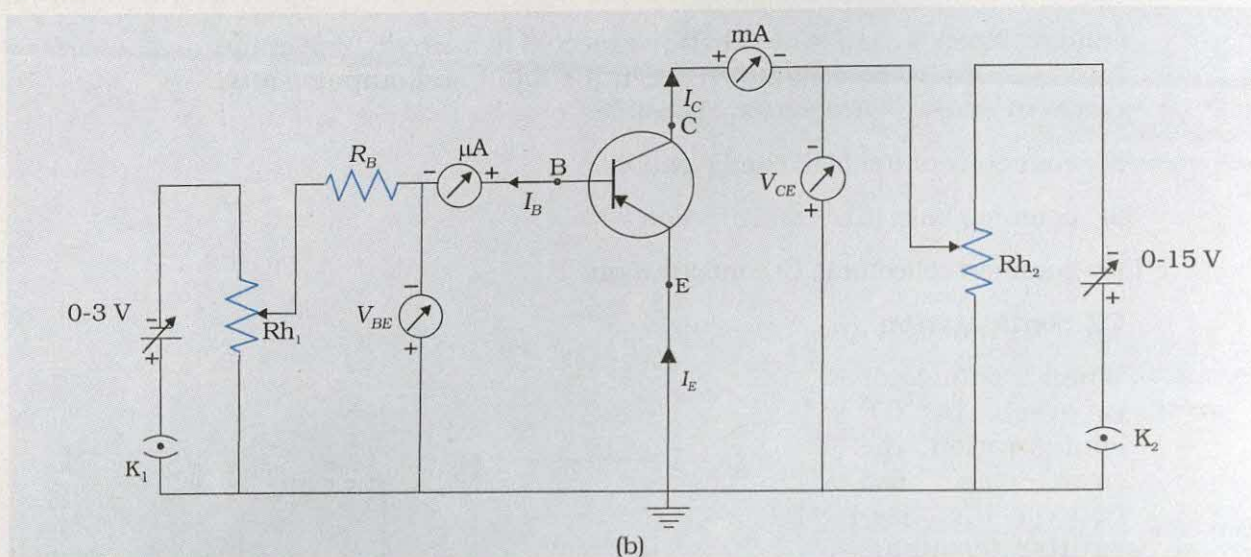


Fig. E 18.3 Circuit diagram for studying the characteristics of (a) n-p-n transistor (b) p-n-p transistor, in CE configuration

circuit diagram for studying the common emitter characteristics of n-p-n and p-n-p transistors respectively. The CE characteristics are of three types:

(I) Input characteristics

The variation of the input current I_B with input voltage V_{BE} keeping output voltage V_{CE} constant is known as input characteristics. As long as the input voltage V_{BE} is less than the knee voltage, current is small and beyond that the current I_B rises [Fig. E 18.4(a)].

Thus, the input resistance r_i is defined as the ratio of change in base - emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔI_B) at constant collector-emitter voltage (V_{CE}). Also, it is defined as the reciprocal of slope at a fixed point on the input characteristics curve i.e.,

$$r_i = \left(\frac{\Delta V_{BE}}{\Delta I_B} \right)_{V_{CE} = \text{const.}} \quad \text{(E 18.1)}$$

The value of r_i is of the order of a few hundred ohms.

(II) Output characteristics

The variation in output collector current I_C with output voltage V_{CE} for different values of input current I_B is known as the output

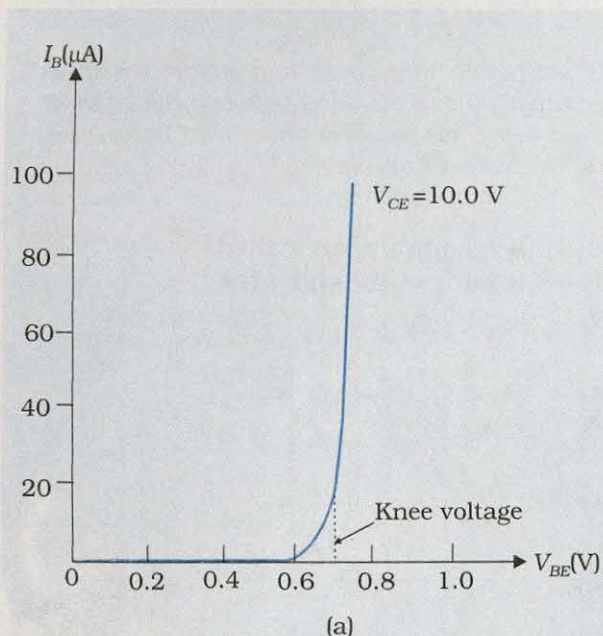


Fig. E 18.4 (a) Typical input characteristics of a transistor in CE configuration

characteristics (Fig. E 18.4 (b)). Greater is the value of input current I_B greater is the output current I_C for a given output voltage V_{CE} .

The output resistance r_o is defined as the ratio of change in collector-emitter voltage (ΔV_{CE}) to the change in collector current (ΔI_C) at constant base current I_B . Further it is also defined as the reciprocal of slope at a fixed point on the output characteristics curve i.e.,

$$(E\ 18.2) \quad r_o = \left(\frac{\Delta V_{CE}}{\Delta I_C} \right)_{I_B = \text{const.}}$$

The values of r_o are of the order of 50 to 100 k Ω .

(III) Transfer characteristics

The variation in output collector current I_C with input base current I_B at constant output voltage V_{CE} is known as the transfer characteristics [Fig. E 18.4(c)]. The current gain β is defined as

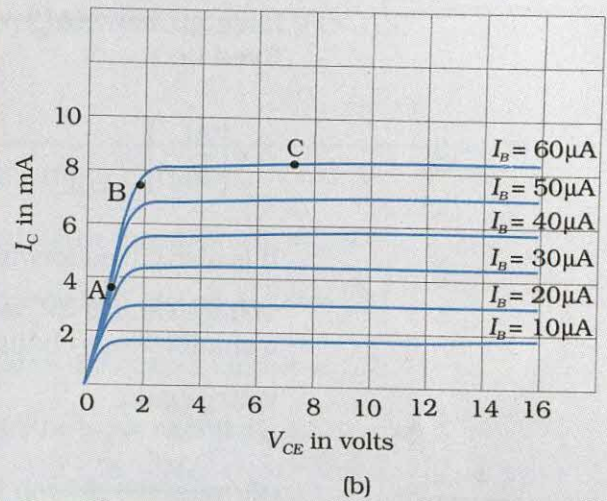


Fig. E 18.4 (b) Typical output characteristics of a transistor in CE configuration

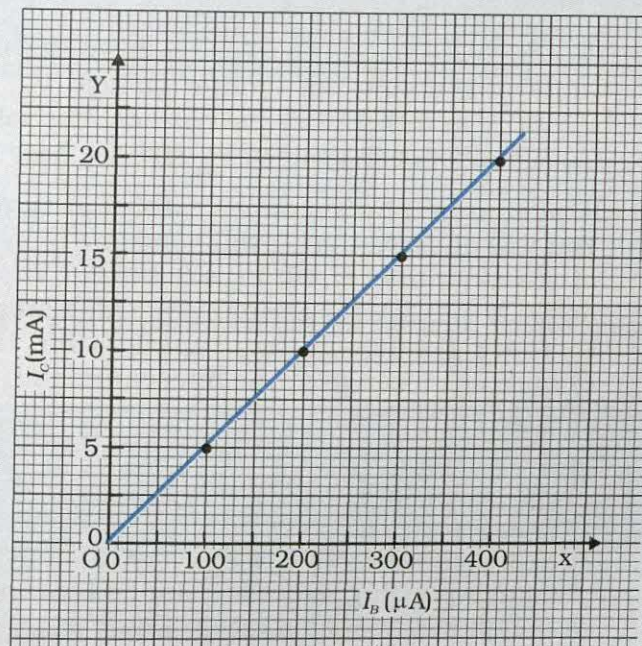


Fig. E 18.4 (c) Typical transfer characteristics of a transistor in CE configuration

the ratio of the change in collector current (ΔI_C) to the change in base current (ΔI_B) when the collector to emitter voltage V_{CE} is fixed i.e.,

(E 18.3)

$$\beta = \left(\frac{\Delta I_C}{\Delta I_B} \right)_{V_{CE}=\text{const.}}$$

It is also called forward current gain.

Voltage Gain: If ΔV_o is change in the output voltage at the collector for a small voltage change ΔV_i in the emitter base,

voltage gain

(E 18.4)

$$A_v = \frac{\Delta V_o}{\Delta V_i} = \frac{\Delta I_C}{\Delta I_B} \frac{r_o}{r_i}; \quad A_v = \beta \frac{r_o}{r_i}$$

PROCEDURE

1. First check whether the given transistor is n-p-n or p-n-p.
2. Connect the circuit as shown in Fig. E 18.3. (Note that the base-emitter junction is forward biased and the collector-base junction is reverse biased. For example, in an n-p-n transistor; base is given a + ve voltage w.r.t. emitter. Also collector is given a high + ve voltage w.r.t. emitter.)
3. To obtain the input characteristics of the transistor, keep the value of the collector-emitter voltage V_{CE} fixed. First adjust $V_{CE} = 0$ V and then vary the base-emitter voltage V_{BE} in steps of 0.1 V and for each value of V_{BE} note the base current I_B .
4. Repeat step 3 by keeping V_{CE} fixed at three different values. You will observe that I_B will continue to be zero for a number of observations i.e., till $V_{BE} = 0.6$ to 0.7 V for silicon transistor and 0.2 to 0.3 V for germanium transistor. Thereafter, it will increase slowly and then rapidly, till I_B is nearly 90 per cent of maximum range of the microammeter.
5. To obtain the output characteristics of transistor, keep the base current I_B at $10 \mu\text{A}$ (say). Note the value of collector current I_C keeping $V_{CE} = 0$ V.

Now increase the value of V_{CE} very carefully in small steps. Note the corresponding values of I_C . (At first the value of I_C will increase very rapidly and then increase slowly to almost a constant value [Fig. E 18.4 (b)]. I_B should be retained constant as noted earlier.

6. Repeat step 5 for three different values of I_B i.e., say 20 μA , 30 μA , 40 μA . You will observe that when I_B increases I_C also increases.

OBSERVATIONS

1. Range of the voltmeter used in the input circuit = ... V to ... V
2. Least count of the voltmeter used in the input circuit = ... V
3. Range of the voltmeter used in the output circuit = ... V to ... V
4. Least count of the voltmeter used in the output circuit = ... V
5. Range of the microammeter used in the input circuit = ... μA to ... μA
6. Least count of the microammeter used in the input circuit = ... μA
7. Range of the milliammeter used in the output circuit = ... mA to ... mA
8. Least count of the milliammeter used in the output circuit = ... mA
9. Specification of the transistor used = ...

Table E 18.1: Variation in input current I_B with input voltage V_{BE} for fixed value of V_{CE}

Sl. No.	Input voltage	Input current, I_B (μA) at			
	$V_{BE} = \dots \text{V}$	$V_{CE} = \dots \text{V}$	$V_{CE} = \dots \text{V}$	$V_{CE} = \dots \text{V}$	$V_{CE} = \dots \text{V}$
1					
2					
--					
5					

Table E 18.2: Variation in output current I_C with output voltage V_{CE} for fixed value of I_B

Sl. No.	Output voltage V_{CE}	Output current I_C (mA) at			
	$V_{CE} = \dots \text{V}$	$I_B = \dots \mu\text{A}$	$I_B = \dots \mu\text{A}$	$I_B = \dots \mu\text{A}$	$I_B = \dots \mu\text{A}$
1					
2					
--					
5					

For transfer characteristics, using Table E 18.2 note the values of I_C corresponding to different values of I_B for a fixed value of V_{CE} .

Table E 18.3: Variation in output current I_C with input current I_B for fixed value of V_{CE}

Sl. No.	Input current	Output current, I_C (mA) at			
	$I_B = \dots \mu\text{A}$	$V_{CE} = \dots \text{V}$	$V_{CE} = \dots \text{V}$	$V_{CE} = \dots \text{V}$	$V_{CE} = \dots \text{V}$
1					
2					
--					
5					

PLOTTING GRAPH

- For input characteristics, plot the graph between input voltage V_{BE} and input current I_B for fixed value of V_{CE} , taking V_{BE} along x-axis and I_B along y-axis, using the readings from Table E 18.1.
- Discuss the nature of V_{BE} versus I_B graph and interpret it.
- For output characteristics, plot the graph between output voltage V_{CE} and output current I_C for fixed value of I_B , taking V_{CE} along x-axis and I_C along y-axis, using the readings from Table E 18.2.
- Discuss the nature of V_{CE} versus I_C graph and interpret it.
- For transfer characteristics, plot the graph between input current I_B and output current I_C for fixed value of V_{CE} , taking I_B along x-axis and I_C along y-axis, using the readings from Table E 18.3.
- Discuss the nature of I_B versus I_C graph and interpret it.

CALCULATIONS

- Draw a tangent on the input characteristics curve at a point on the rapid rising portion [Fig. E 18.4(a)], and from it, determine the reciprocal of slope of the curve at that point. This gives the dynamic input resistance, of the transistor

$$r_i = \left(\frac{\Delta V_{BE}}{\Delta I_B} \right)_{V_{CE} = \text{const.}}$$

- Draw tangents on the output characteristics curve (at linearly rising part A, at turning point B and nearly horizontal part C)

[Fig. E 18.4(b)]. Measure the reciprocal of slopes which will give the dynamic output resistances,

$$r_o = \left(\frac{\Delta V_{CE}}{\Delta I_C} \right)_{I_B = \text{const.}}$$

at operating points A, B and C [Fig. E18.4(b)]. Note that the dynamic output resistance depends on the operating point.

- (iii) Find the slope on the transfer characteristics of the transistor to obtain current gain β of the transistor as

$$\beta = \left(\frac{\Delta I_C}{\Delta I_B} \right)_{V_{CE} = \text{const.}}$$

- (iv) Take the values of input resistance r_i , output resistance r_o and current gain β and calculate the value of voltage gain A_v of the transistor by using the relation

$$A_v = \beta \left(\frac{r_o}{r_i} \right)$$

RESULT

For the given transistor (...) in the common emitter (CE) configuration

1. The characteristics of the transistor are shown in the graphs drawn.
2. At $V_{CE} = \dots V$ input resistance = $\dots \Omega$
3. At $V_{BE} = \dots V$ output resistance = $\dots \Omega$
4. Current gain, $\beta = \dots$
5. Voltage gain, $A_v = \dots$

PRECAUTIONS

- (i) Biasing of the transistor should be done considering whether the transistor is n-p-n or p-n-p.
- (ii) Key should be plugged out to break the circuit when circuit is not in use.

DISCUSSION

1. Is there any change in characteristic curves if we use a p-n-p transistor instead of n-p-n transistor?
2. Why is the input circuit forward biased and output circuit reverse biased?
3. You notice the dynamic output resistance r_o is different for different regions of the output characteristic curve. What do you infer from this?
4. If you use some input resistance say $200\ \Omega$ at the input then the characteristic curves are called dynamic input characteristics of a CE transistor. The resistors used in the circuit are basically to control the current so as to avoid the burning out or any damage to the transistor. If no resistor is used in the circuit and the experiment is performed, then the characteristics curves are known as the static input characteristics and static output characteristics. While obtaining the static characteristics, extra care has to be taken to avoid any damage to the transistor due to large flow of current beyond the permissible limits.

SELF ASSESSMENT

1. What do you mean by dynamic input resistance and why is it called dynamic?
2. For CE configuration, I_C is not cut-off even for $I_B = 0$. For determination of the cut-off voltage in CE mode, how will you reduce I_C to zero?
3. Is I_C almost independent of V_{CE} for $V_{CE} > V_{BE}$ in CE configuration?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

Connect the n-p-n transistor in common base configuration. Draw the characteristic curves. Compare input and output characteristic curves of CB and CE configurations. Also find r_i and r_o .

ACTIVITIES

ACTIVITY

1

A_{IM}

To assemble the components of a given electrical circuit.

A_{PPARATUS AND MATERIAL REQUIRED}

Resistor, ammeter, (0-1.5A) voltmeter (0-5V), battery, one way key, rheostat, sand paper, connecting wires.

P_{ROCEDURE}

1. Connect the components as shown in Fig. A 1.1.
2. After closing the key K, check that the voltmeter and ammeter show deflections on the right hand side.
3. Check the continuity of the assembled circuit using a multimeter (see Activity 4).

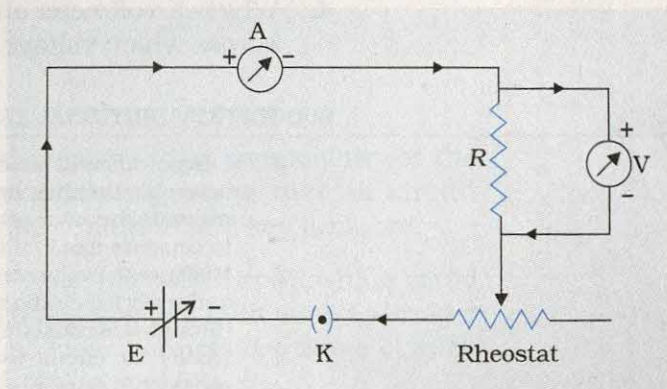


Fig. A 1.1 Assembling of given components

R_{ESULT}

The components of the electrical circuit were assembled.

P_{RECAUTIONS}

1. The positive terminal of the battery should be connected to the positive terminal of ammeter and positive terminal of the voltmeter.
2. The ammeter should be connected in series with the resistor and the voltmeter should be connected in parallel with the resistor.
3. Sand paper should be used to clean the ends of connecting wires and leads of the component terminals. Grease/oil or oxide layer

on their surfaces is insulating in nature and needs to be removed. However, do not clean the plugs and keys with sand paper. Excessive use of sand paper in such a case will make the plug unfit to be used with the key.

DISCUSSION

1. Draw the circuit diagram of the experiment before you start connecting apparatus and keep in front of you.
2. The values of the resistances and the current carrying capacity of the rheostat are given on a plate fixed on the body of rheostat.

SELF ASSESSMENT

1. What do you mean by emf of a cell?
2. Does the current drawn from the cell remain constant? If not, why?
3. Why is an ammeter always connected in series with the circuit?
4. Why is a voltmeter always connected in parallel to the component across which voltage is to be measured?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Design different kinds of circuits that you will study in your class and assemble them using the relevant components, for example (i) circuit to measure the value of an unknown resistance using a meter bridge (ii) circuit to compare e.m.f. of two cells using a potentiometer, etc.
2. Measure the voltmeter and ammeter readings for different rheostat settings and verify if the ratio of potential difference across the resistor to the current through it is constant.
3. Modify the circuit using two resistors which may either be connected in series or in parallel.

AIM

To draw the diagram of given open circuit comprising atleast a battery, resistor/rheostat, key, ammeter and voltmeter. Mark the components that are not connected in proper order and correct the circuit and also the circuit diagram.

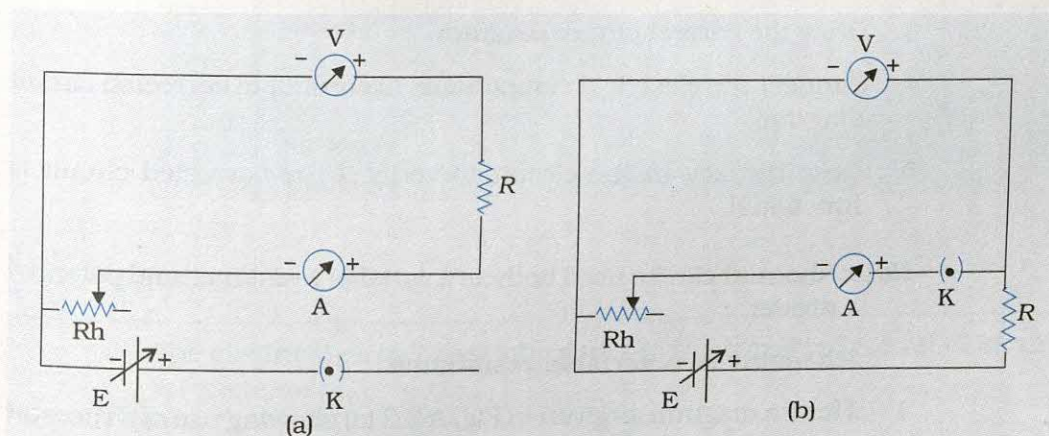
APPARATUS AND MATERIAL REQUIRED

A given open circuit comprising atleast a cell or a battery, plug key, resistor, rheostat, ammeter, voltmeter, connecting wires and sand paper.

PRINCIPLE

An electrical circuit is functional only if all the components of the circuit are connected in proper order, assuming that all circuit components/devices are in working condition and key is closed.

An open circuit means a break in some part of a circuit which could be deliberate such as a key in open position or a fault such as broken wire or burnt out component(s) or loose connection. Some of such circuits are given in Figs. A 2.1 (a), (b), (c) and (d).



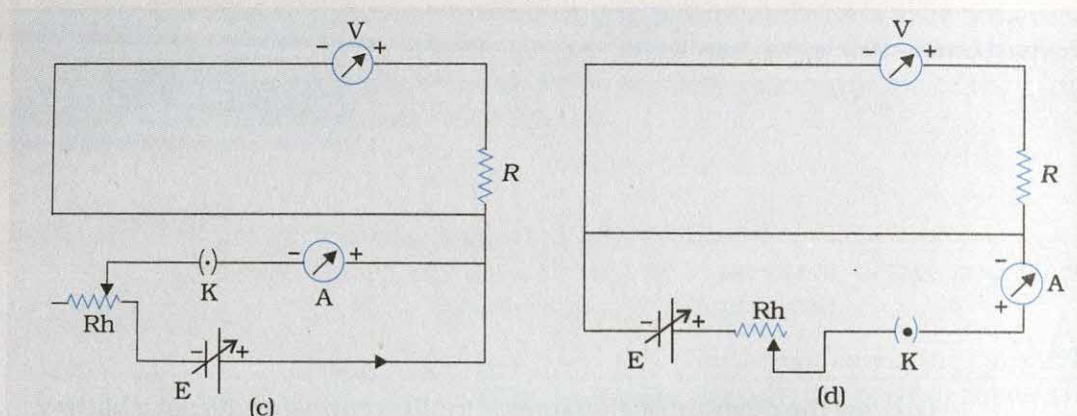


Fig. A 2.1 (a),(b),(c),(d) Open circuits

Note to teachers: In this activity, students are expected to draw the diagram of a given open circuit comprising a few circuit components e.g. a key, ammeter, voltmeter, resistor, rheostat etc. After drawing the given circuit, students would be marking the components which are not connected in proper order. Then a correct circuit diagram is to be drawn and accordingly the circuit components are to be connected in proper order.

Teachers are therefore advised to set up a few open circuits in which some of the components are not arranged in proper order.

PROCEDURE

1. Draw the circuit diagrams in your notebook as given by your teacher [Fig. A 2.1(a), (b), (c) and (d)].
2. Consider one circuit and mark in Table A 2.1, the various components which have not been connected in proper order.
3. Draw the correct circuit diagram.
4. Connect the electrical components according to corrected circuit diagram.
5. Close the key in the circuit to verify if the corrected circuit is functional.

Note: Rheostat can be used both as a variable resistance and potential divider.

Rheostat as a variable resistance

1. Draw a diagram as given in Fig. A 2.2 (a) showing use of a rheostat as a variable resistor.

- Connect the terminals of rheostat as drawn below using one end terminal and the other variable terminal.

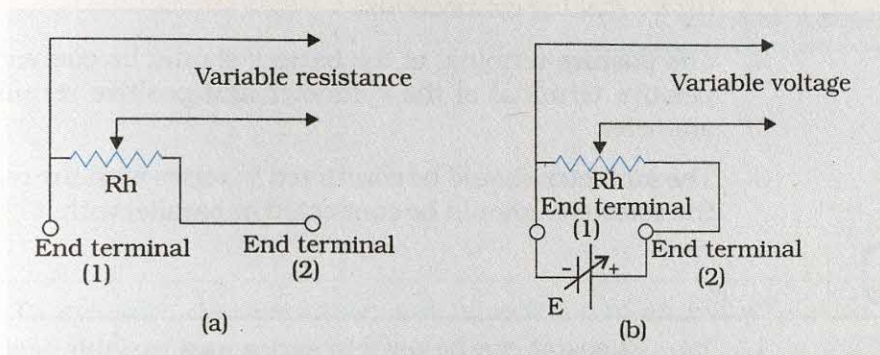


Fig. A 2.2 (a) Rheostat as a variable resistor
(b) Rheostat as a potential divider giving variable voltage

Rheostat as a potential divider

- Draw a diagram as given in Fig. A 2.2 (b) showing use of a rheostat as a potential divider.
- Connect the terminals of rheostat as drawn above using (i) the end terminals (1) and (2) connected to input potential (battery) and (ii) one end terminal and the other variable terminal for variable voltage.

OBSERVATIONS

Table A 2.1: Mark a (✓) in appropriate column

Sl. No.	Circuit Component	Correct Connection	Incorrect Connection
1	Battery/cell		
2	Resistor		
3	Rheostat		
4	Key		
5	Ammeter		
6	Voltmeter		

RESULT

The electrical circuit assembled as per the corrected circuit diagram is functional.

P RECAUTIONS

1. Ends of the connecting wires should be cleaned with sand paper before making connections.
2. The positive terminal of the battery should be connected to the positive terminal of the voltmeter and positive terminal of the ammeter.
3. The ammeter should be connected in series with the resistor and the voltmeter should be connected in parallel with it.

D ISCUSSION

1. (a) Rheostat can be used in series as a variable resistance. In this case, the end terminal (1) and the other variable terminal is to be used [Fig. A 2.2(a)].
(b) When rheostat has to be used as a potential divider across the cell, the variable voltage is derived using any one end-terminal and the variable terminal of the rheostat [Fig. A 2.2(b)].

Justify how the discussion points 1(a) and 1(b) are possible?

2. Key is to be kept "OPEN" so that no damage to the components occur.

S ELF ASSESSMENT

1. Interpret the function of each component in the circuit.
2. Draw a circuit diagram of a rheostat as a variable resistance showing the position of sliding contact for (i) maximum resistance (ii) minimum resistance.
3. What is the function of sand paper in setting up the electric circuit?
4. A rheostat and a resistance box can change the resistance in a circuit, yet their functions are different. Discuss it.

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Draw a circuit diagram using rheostat as a potential divider. Make actual connection and determine the voltage range it provides.
2. Study the different kinds of keys available in the laboratory and identify their functions in the electric circuit.
3. Make a detailed study of different types of resistances available in the laboratory (carbon resistor, wire wound resistance box).
4. Compare the connecting wires used in household circuits and those used in the laboratory.
5. Make a study of different battery eliminators, dc sources (cells, batteries) in the laboratories. How are they different as compared to car batteries?

AIM

To measure the resistance and impedance of an inductor with or without iron core.

APPARATUS AND MATERIAL REQUIRED

Inductor coil (diameter about 2 cm and 2000 turns), soft iron core (cylindrical rod of diameter about 1.75 cm and length equal to that of inductor), resistance box (0 to 10,000 ohm), battery eliminator (0-2-4-6 volt), a step down transformer with tapings (0-2-4-6 volt, 50 Hz), dc milliammeter (range 0 - 500 mA), ac milliammeter (range 0 - 500 mA), dc voltmeter (range 0 - 5 V), ac voltmeter (range 0 - 5 V), one way key, connecting wires.

PRINCIPLE

An inductor is a cylindrical coil of very large number of turns of copper wire usually wound on a hollow cylinder. The resistance of such coil is given as

$$R = \frac{V}{I}$$

(A 3.1)

where V is the potential difference across the coil and I is the dc current through that coil. On introducing the core of soft iron, the new values of potential difference across the coil, V' and the current, I' through it are measured again. The resistance of the coil with iron core becomes

$$R' = \frac{V'}{I'}$$

(A 3.2)

The resistance offered by the coil to the flow of alternating current is known as impedance Z . If V_{ac} and I_{ac} respectively be the alternating voltage and alternating current through the coil, without iron core, then the impedance of the coil, is given as

(A 3.3)

$$Z = \frac{V_{ac}}{I_{ac}}$$

On introducing the iron core inside the coil, the value of the impedance Z' becomes

(A 3.4)

$$Z' = \frac{V'_{ac}}{I'_{ac}}$$

where, V'_{ac} is the alternating voltage across the inductor with core inside and I'_{ac} is the alternating current through the inductor with core inside.

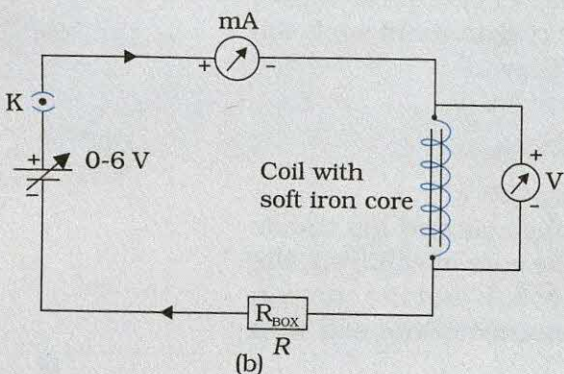
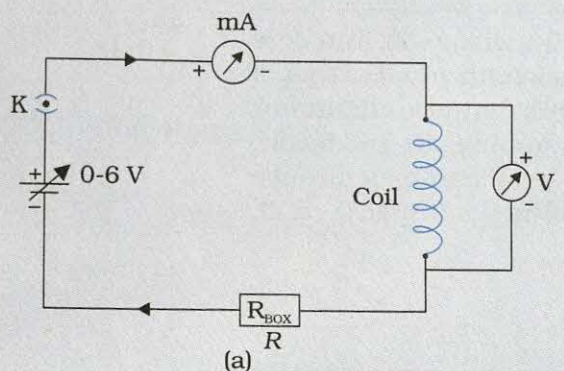


Fig. A 3.1 Inductor in a dc circuit: measurement of resistance with (a) an air core (b) a soft iron core

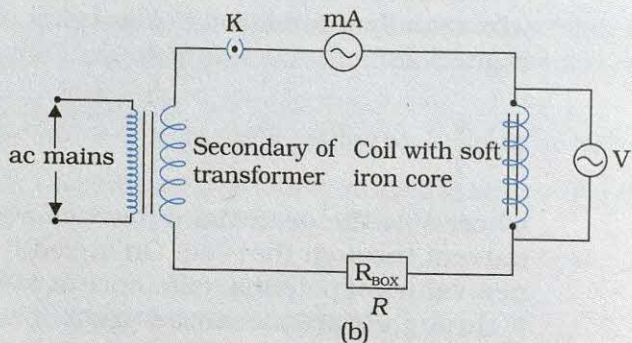
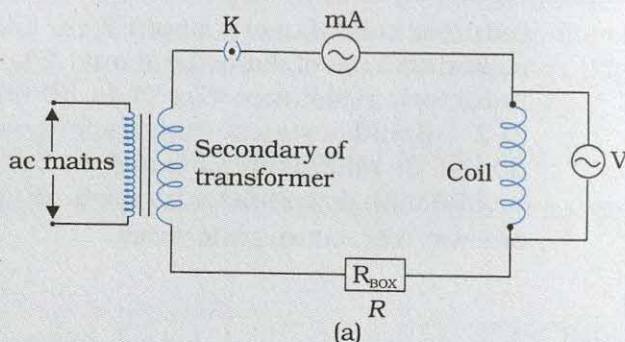


Fig. A 3.2 Inductor in an ac circuit: measurement of impedance with (a) air core (b) soft iron core.

PROCEDURE

1. **For resistance of inductor without iron core**, arrange the apparatus as per the circuit diagram Fig. A 3.1 (a) by keeping the key K open.
2. Connect the dc source and dc milliammeter in series with inductor and voltmeter in parallel with it.
3. Adjust the battery eliminator to the lowest setting and switch on the eliminator. Plug in the key. Adjust R so that the readings are within scale. Measure the dc current and dc voltage across the inductor.
4. Set the eliminator to higher voltages in succession and record the dc current and dc voltage across the inductor.
5. **For resistance of inductor with soft iron core**, introduce the iron core such that it is fully inside the coil. [Fig. A 3.1(b)].
6. Repeat steps 3 and 4 and record the current and voltage across the inductor.
7. **For measurement of impedance of inductor without iron core**, use step down transformer with various tapings (2V, 4V, 6V), ac voltmeter (0-5V) and ac ammeter (0-0.3A) and connect them as shown in Fig. A 3.2(a).
8. Repeat steps 3 and 4 and for alternating current and alternating voltage. Record the current and voltage across the inductor.
9. **For measurement of impedance of inductor with soft iron core**, introduce the core of the soft iron inside the coil such that the core is fully inside the coil. [Fig. A 3.2(b)].
10. Repeat steps 3 and 4 for alternating current and alternating voltage. Record the current and voltage across the inductor.

OBSERVATIONS

1. Range of dc voltmeter = 0 to...V
2. Least count of dc voltmeter = ...V
3. Range of dc ammeter = 0 to...mA
4. Least count of dc ammeter = ...mA
5. Range of ac voltmeter = 0 to...V
6. Least count of ac voltmeter =...V
7. Range of ac ammeter = 0 to...mA
8. Least count of ac ammeter =...mA

Table A 3.1: Resistance of the inductor without and with iron core

Sl. No.	Battery Eliminator Setting	Without iron core			With iron core		
		Voltage	Current	$R = \frac{V}{I}$	Voltage	Current	$R' = \frac{V'}{I'}$
		V (V)	I (mA)	R (Ω)	V' (V)	I' (mA)	R' (Ω)
1							
2							
3							
4							
Mean					Mean		

Table A 3.2: Impedance of the coil without and with iron core

Sl. No.	Setting of ac voltage source	Without iron core			With iron core ac voltage		
		Voltage	Current	$Z = \frac{V}{I}$	Voltage	Current	$Z' = \frac{V'}{I'}$
		V (V)	I (mA)	Z (Ω)	V' (V)	I' (mA)	Z' (Ω)
1							
2							
3							
4							
Mean					Mean		

CALCULATIONS

1. Calculate the ratio of voltage and current for each observation to get resistance and impedance.
2. Calculate the mean values of the resistance and impedance in each case, i.e., without and with iron core.

RESULT

1. The dc resistance of the inductor coil without iron core = ... Ω
2. The dc resistance of the inductor coil with iron core = ... Ω
3. The impedance of the inductor coil without iron core = ... Ω
4. The impedance of the inductor coil with iron core = ... Ω

PRECAUTIONS

1. The ammeter should be connected in series with the coil and the voltmeter in parallel with it.
2. The iron core should be inserted completely within the coil.
3. The ends of the connecting wires should be cleaned with sand paper before making the connections.

SOURCES OF ERROR

The least count of the ac milliammeter and ac voltmeter may not be small enough to accurately record the difference in impedance on inserting the iron core.

SELF ASSESSMENT

1. What is meant by impedance of a circuit?
2. What differences do you observe in dc and ac ammeters and voltmeters?
3. If iron core of the inductor coil is taken out, what effect will it have on the readings of the ammeter and voltmeter and why?

DISCUSSION

1. Compare the dc resistance of the coil with and without iron core. It will be found that there is no change in the resistance of the coil on introduction of iron core. Explain the result.
2. Compare the impedance of the coil with and without iron core. It will be observed that the impedance increases on introduction of iron core. Explain the result.

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Repeat the ac measurement with wooden, plastic or copper cores (which may have any length). Do you see any change in impedance on introduction of such cores?
2. If the iron core is not fully inside, do you get the same change in impedance?

AIM

To measure resistance, voltage (dc/ac), current (dc) and check continuity of a given circuit using a multimeter.

APPARATUS AND MATERIAL REQUIRED

A multimeter with its test leads, a resistance box, a key, a cell, a step-down transformer of 6 V output voltage, a rheostat, connecting wires and a piece of sand paper.

(Note to teachers: Do not allow students to handle alternating current sources of 220 V for safety considerations.)

Description of multimeter: A multimeter is an instrument that can work as a current meter (ammeter) or a voltage meter (voltmeter) or a resistance meter (ohmmeter). Sometimes it is also referred to as AVO (ampere, volt and ohm) meter. It may measure resistance and potential difference in both ac and dc circuits and current in dc circuit over several ranges. The function and the range can be selected by means of either a rotary selector knob or a combination of switches and sockets.

Multimeters are of two kinds : analog and digital.

Analog multimeter : Analog multimeter Fig. A 4.1 (a) is a dc galvanometer which can be converted into an ammeter or a voltmeter of different ranges to measure current or voltage or resistance. For ac measurement, the root mean square (*rms*) values of current and voltage are measured.

When using a multimeter to measure current, it must be connected in series with the circuit. For measuring the voltage difference between two points in a circuit, the two leads of the multimeter are connected across them. For example, to measure the voltage across a resistor, the multimeter is connected in parallel with the resistor.

When the multimeter is in the resistance measuring mode, a cell within the multimeter automatically gets connected, which makes the current flow through the externally connected resistor whose resistance is being measured. The multimeter only senses

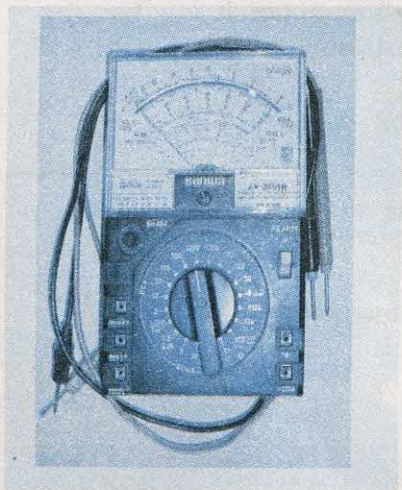


Fig. A 4.1(a) Analog multimeter

this current with its dial calibrated in terms of the resistance. It is essentially nonlinear in calibration.

Digital multimeter : Fig. A 4.1(b) shows a digital multimeter.

To measure voltage and current it uses a digital circuit called ADC (analog to digital converter). Since the ADC can accept a very small input voltage, a sampling of the input voltage/ current is necessary.

Voltage is measured directly, whereas current is converted into proportional voltage using standard resistors built in the instrument.

For resistance measurement, constant current sources are used. It creates voltage proportional to resistance values which is then digitised by the ADC.

The resolution of such meters depends on the range as well as the number of digits in the display panel.



Fig. A 4.1(b) Digital multimeter

P RINCIPLE

When the resistance R is connected in a circuit, for example as shown in Fig. A 4.2, the potential difference across the two end points of the resistor can be measured by connecting the multimeter (with proper voltage setting) in parallel with the resistor.

The coil of the multimeter shows a deflection proportional to the direct current (dc) passing through it. Measurement of alternating current is based on the principle of heating effect of current.

The current flowing through the resistor can be measured by connecting the multimeter (with proper current setting) in series as shown in Fig. A 4.5.

The continuity of any electrical component can be checked by measuring the resistance of the component. An infinite resistance across the two ends of a component

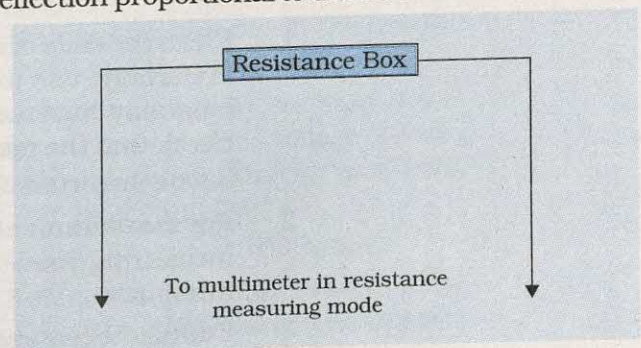


Fig. A 4.2 Use of multimeter as a resistance meter

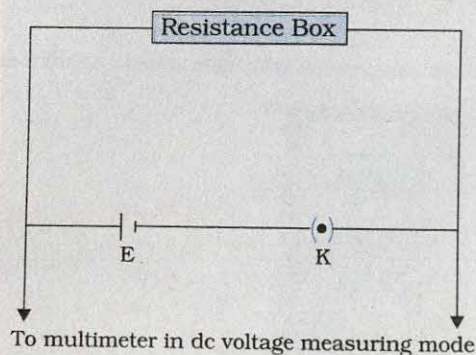


Fig. A 4.3 Use of multimeter as a dc voltmeter

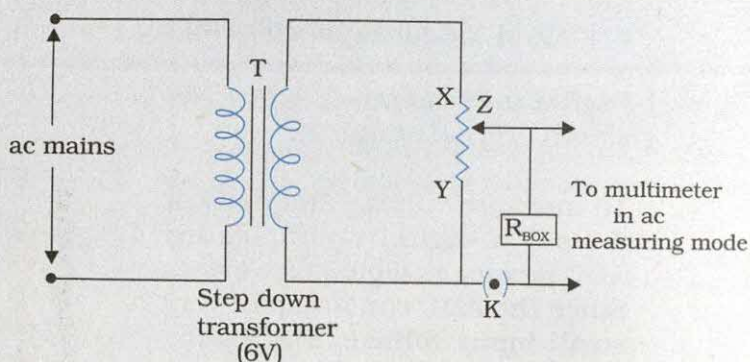


Fig. A 4.4 Use of multimeter as ac voltmeter

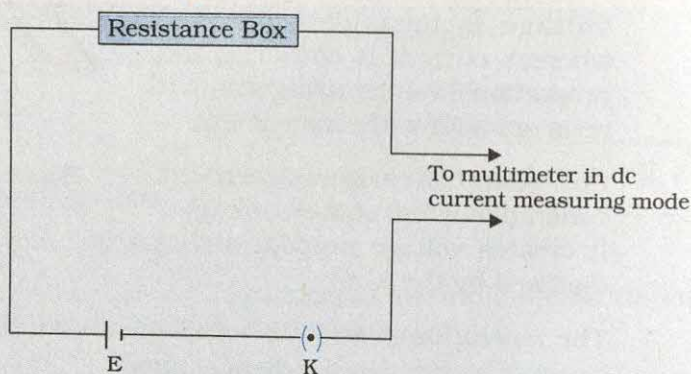


Fig. A 4.5 Use of multimeter as an ammeter

indicates a discontinuity. A very low resistance ($\leq 0.1 \Omega$) between the two ends of a component indicates that the component under test has a short circuit. (Fig. A 4.2).

PROCEDURE

Analog multimeter

1. Clean the ends of connecting wires by a sand paper till they shine. Preferably, use fresh connecting wires, as wires not in use for long may have some insulating layer deposited on them. Also check that the metallic ends of the multimeter test leads are not having any rust or any insulating layer deposited on them.
2. **For measurement of resistance:** set the multimeter in resistance measuring mode. Connect the red and black probes to the multimeter.
3. Connect open end of the red probe directly to the black probe and adjust the zero adjustment knob to read zero ohm on the resistance scale (extreme right).
4. Separate the two metallic ends of the test probes and connect the resistance box with the multimeter as shown in Fig. A 4.2.

5. Insert a resistor of known resistance R in the circuit by taking out the corresponding resistor key from the resistance box and read multimeter reading R_M for the value of resistance of the resistor used in the circuit. Repeat this step for four more resistors.
6. Carefully observe the reading in the non-linear scale noting that its zero lies at the extreme right of the scale. Use the multiplication factor appropriately to the range selected.
For example: 4 divisions of deflection in $R \times 100$ scale means resistance measured is $4 \times 100\Omega = 400\Omega$.
7. **For measurement of dc voltage:** select the suitable position of the function switch (ac/dc) and then select the highest range available. Ensure that the test probes are inserted/ connected in sockets with proper polarity. It is a convention to use red probe for positive and black probe for negative polarity.
8. Connect the multimeter in the circuit as shown in Fig. A 4.3.
9. Set the multimeter to measure the dc voltage. Select a suitable range. For example, if a cell of 1.5V emf (say) is used in the circuit, keep the range at 2.5V.
10. To measure the emf of the cell, connect the positive terminal of the multimeter to the positive terminal of the cell and negative terminal to negative terminal of the cell, through a plug key K. Do not insert any resistor of resistance R in the circuit from the resistance box. Insert the key in the plug K of the circuit and read the multimeter reading. (A continuous flow of current in the circuit will heat the connecting wires). Record your observations in Table A 4.2. Then open the key K.
11. Now insert a resistance R of known value (10 Ω say) by taking out the resistance key from the resistance box in the circuit. Insert the key in the plug K. Read the multimeter reading for measuring the potential difference across the two ends of the resistor. Do you find any change in the reading as observed in step 10 when there was no resistance in the circuit (i.e. $R = 0$)?
12. Repeat step 11 for three more values of resistance in the circuit. Record your observations in Table A 4.2.
13. **For measurement of ac voltage:** connect an ac step down transformer of 6 V output voltage, a rheostat XY as voltage divider, resistance box R_{BOX} , a plug key K, and the multimeter as shown in Fig. A 4.4. Fix the value of R to be 5 ohm (say).
14. Set the multimeter to act as an ac voltmeter at 10V range.
15. Bring the variable connector Z of the rheostat close to point X. In this situation the resistance of rheostat coil would be minimum. Close the key in the plug K and record the multimeter reading for ac voltage drop across the resistor of resistance R in Table A 4.3. Repeat the observations for atleast four positions of the variable connection (Z) of the rheostat on coil XY (Table A 4.3).

Note to students: Please do not handle alternating current sources of 220 V for safety considerations.

16. **For measurement of dc current:** select the function switch and the range switch/sockets suitable for proper dc current measurement. For example, if one cell of 1.5 V emf is used in the circuit as a source and the value of resistance to be used during the experiment varies from $2\ \Omega$ to $10\ \Omega$, a range of 1A (or 1000 mA) would be appropriate.
17. Insert the probes of the multimeter in series with the cell so that the positive terminal of the multimeter is connected to the positive terminal of the cell and negative terminal of the multimeter with the negative terminal of the cell as shown in Fig. A 4.5.
18. Read the multimeter reading for measuring the dc current flowing through the multimeter.
19. Bring a resistance (R) in the circuit and read multimeter reading for measuring the current flowing in the circuit after closing the key in plug K. Repeat it for four more values of resistance (R) in the circuit. Record the observations in Table A 4.4.

Digital multimeter

Procedure for measuring voltage, current and resistances is very similar to that of the analog measurement. The notable difference is that digital multimeter is not vulnerable to damage as easily as their analog counterparts. They can accept voltage with reversed polarities (shown by positive and negative sign), and display the number as and when the magnitude of the measured quantity crosses the upper limit of the range used.

There are no adjustments required (on any of the ranges) for measuring R .

OBSERVATIONS

1. Range of resistance scale on the multimeter panel =... Ω
2. Least count of the scale =... Ω

Table A 4.1 : Measurement of resistance

Sl. No.	Resistance R as indicates in resistance box (Ω)	Multimeter reading R_M (Ω)	Difference $R - R_M = [R - R_M]$ (Ω)
1			
2			
...			
5			

Range of dc voltage scale selected on the multimeter panel = ... V

Least count of the scale = ... V

Table A 4.2 : Measurement of dc voltage

Sl. No.	Resistance R in the circuit (Ω)	Multimeter reading for voltage (V)
1		
2		
--		
5		

Range of ac voltage scale selected on the multimeter panel = ...V

Least count of the scale = ...V

Table A 4.3 : Measurement of ac voltage drop across a resistor of resistance $R = \dots\Omega$

Sl. No.	Position of variable connection of the rheostat on coil XY	Multimeter reading (V)
1	Close to point X	
2		
--		
5	Close to point Y	

Range of dc current scale selected on the multimeter panel = ... mA

Least count of the scale = ... mA

Table A 4.4 : Measurement of dc current

Sl. No.	Resistance R in the circuit (Ω)	Multimeter reading for current (mA)
1		
2		
--		
5		

RESULT

1. The dc/ac voltage, dc current and resistance have been measured using a multimeter.

2. The values of resistance measured by the multimeter is nearly the same as the decoded values of resistors.

PRECAUTIONS

1. Appropriate selection of function switch and range switch for a given measurement of voltage or current and resistance should be made.
2. The polarity probe leads should be connected to the proper polarities in measuring dc voltage and current.

SOURCES OF ERROR

1. The scale used in reading of voltage/ current may be improper.
2. Zero adjustment in measuring R with analog multimeter may not be accurate.

DISCUSSION

1. If in place of a resistance box, carbon resistors are used, the heating of carbon resistor should be avoided. Heating of resistors may change the resistance value of the resistor.
2. The percentage error in the measurement is more for smaller values of the measured quantity.
3. If the two test leads of the multimeter are not identical, and also there is significant resistance across the junctions of the multimeter (test leads and the test resistance), how is your measurement going to be affected?

SELF ASSESSMENT

Can the measurement of dc voltage/ current be done using ac voltage/ current function switch? Justify your answer.

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

A collection of assorted colour coded resistors are provided to you. Verify the decoded values using multimeter within the tolerance limit specified by the code on the resistor.

AIM

To assemble a household circuit comprising three bulbs, three (on/off) switches, a fuse and a power source.

APPARATUS AND MATERIAL REQUIRED

Three bulbs (40 W, 220 V each), three (on/off) switches, socket, a fuse of 1.0 A, plug, flexible connecting wire, main switch.

PRINCIPLE

If $P_1, P_2, P_3, P_4, P_5, \dots$ be the power consumed by different domestic electrical appliances in a circuit then the total power consumption, P at any instant is given by

$$P = P_1 + P_2 + P_3 + P_4 + P_5 + \dots$$

(A 5.1)

If electric potential is V , then current I drawn from the mains is given by

$$I = \frac{P}{V}$$

(A 5.2)

where P is in watt, V in volt and I in ampere.

In order to protect the appliances from damage, when accidentally a high current is drawn (e.g. when the terminals of the appliance get accidentally connected), a fuse of rating little higher (10 to 20 per cent higher than the current normally drawn) is connected in series with the set of appliances (Fig. A 5.1).

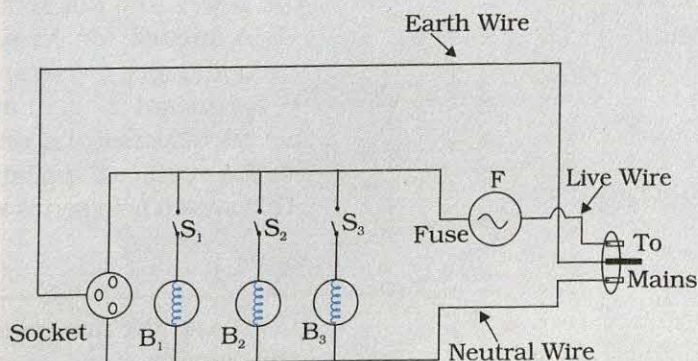


Fig. A 5.1

PROCEDURE

1. Take the bulbs B_1 , B_2 , B_3 and connect them in series with switches S_1 , S_2 and S_3 respectively. Connect B_1 , B_2 , B_3 alongwith S_1 , S_2 , S_3 in parallel with each other as shown in Fig. A 5.1.
2. Connect fuse F in series with the set up as shown in Fig. A 5.1. Connect a plug and the socket at the end of two leads. Connect a wire from the earth pin of the plug.
3. Insert the plug in socket provided in the main electric board.
4. Press the switches S_1 , S_2 , S_3 one by one and observe the bulb that is switched on and off independently of the other bulb.
5. Press all the switches simultaneously and observe what happens. Record your observations.

RESULT

Household circuit assembly is complete and installed with safety.

PRECAUTIONS

1. Care should be taken while working with mains.
2. Carefully determine the rating of the fuse by calculating the maximum current drawn by the circuit.

DISCUSSION

1. Fuse is a safety device. Never use fuse of much higher rating than the recommended value.
2. The rating of the main electricity in our houses is determined by the total power requirements. In general it is 220 V, 30 A and 50 Hz. The supply is connected to a distribution board which divides the power into different circuits; some having a rating of 220 V, 15 A meant for heavy duty appliances like room heater, airconditioner, geysers, hot plates etc., others have a rating of 220 V, 5 A meant for light appliances like light bulbs, ceiling fans etc. Let us consider one electrical circuit with 220 V, 5 A supply. In such a circuit all appliances are connected in parallel with a switch. This switch is in series with each appliance in supply live line.

SELF ASSESSMENT

1. Calculate the maximum current drawn for three bulbs used in the circuit.

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Draw a circuit diagram consisting of two light points, one fan point and one plug point.

AIM

To study the variation in potential drop with length of a wire for a steady current.

APPARATUS AND MATERIAL REQUIRED

Potentiometer, battery eliminator of constant voltage, dc power supply or lead accumulator, voltmeter and ammeter of suitable range, plug key, jockey, rheostat, connecting wires, etc.

PRINCIPLE

If a steady current is flowing through a wire of uniform area of cross section and having its resistance per unit length constant, potential drop V across two points of the wire is directly proportional to the length l between those two points.

Mathematically, $V \propto l$

PROCEDURE

1. Set up the electrical circuit as shown in Fig. A 6.1.
2. Connect positive terminal of the battery to point A (zero length) of the potentiometer.
3. Connect negative end of the battery to the other end B (point) of the potentiometer wire through an ammeter, plug key and a rheostat. The ammeter

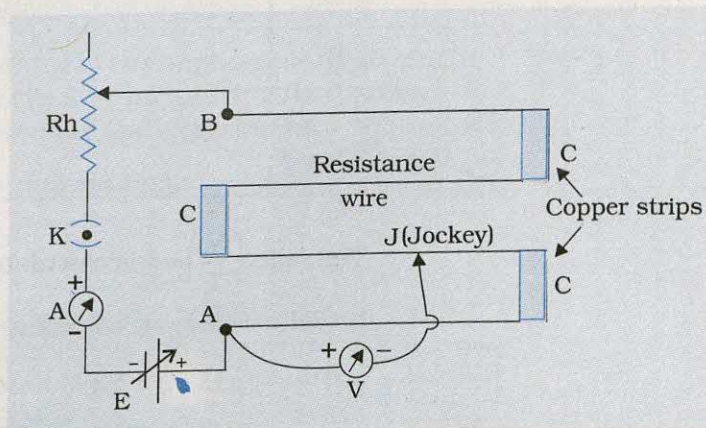


Fig. A 6.1 Circuit to study variation in potential drop

should be connected in such a way that its negative terminal is connected to the negative terminal of the battery.

4. Connect positive end of the voltmeter to point A and other end to a jockey J.
5. Now close the key K and press the jockey at point B. Adjust the rheostat to get full scale deflection in voltmeter.
6. When jockey is pressed at point A, you will get zero deflection in the voltmeter.
7. Now press the jockey at 40 cm and note the corresponding voltmeter reading.
8. Repeat your observation by pressing the jockey at various lengths like 80 cm, 120 cm etc. which may extend upto, say 400 cm of potentiometer wire. Record voltmeter reading in each case as shown in Table A 6.1.

OBSERVATIONS

Range of the voltmeter = ... V

Least count of the voltmeter = ...V

Zero error = ... V

Table A 6.1: Variation in potential drop with length

Sl. No.	Length of potential wire over which potential drop is measured l (cm)	Voltmeter reading V (V)	$\phi = V/l$ ($V\text{ cm}^{-1}$)
1			
2			
..			
5			
Mean			

CALCULATIONS

The ratio $\left(\frac{V}{l}\right) = \phi$ is calculated. It is the potential gradient of the wire.

Its value is almost constant.

PLOTTING GRAPH

Plot a graph of V versus l , with V on y-axis and l on x-axis. Slope of the line gives ϕ .

RESULT

The ratio $\left(\frac{V}{l}\right) = \phi$ is found to be constant within the limits of experimental error. Its mean value is... $V\text{ cm}^{-1}$.

The graph shows a linear relationship between V and l . The value of $\left(\frac{V}{l}\right) = \phi$ from the graph is ... $V\text{ cm}^{-1}$.

PRECAUTIONS

1. Zero error in the voltmeter or ammeter (if there is any) should be corrected by adjusting the screw provided at the base of the needle.
2. The current in the wire should remain constant throughout the experiment. To ensure this, current should be drawn intermittently for short duration of time. It should be monitored by an ammeter and readjusted whenever necessary, with the help of a rheostat.
3. Do not press the wire too hard with the jockey while noting down the observations or else there is a possibility that the wire will become non-uniform (diameter will change) at these points during the course of time.
4. Check for uniformity of wire at its various points before the start of the experiment. If wire is non-uniform, the potential gradient will not be constant.

SOURCES OF ERROR

1. The wire must have a uniform cross section along its entire length. This should be checked by measuring its diameter at various points before the start of the experiment.
2. Voltmeter may not give accurate reading.

DISCUSSION

1. The potentiometer wire is connected firmly to thick copper strips after every 100 cm of its length of 400 or 1000 cm. However, these small sections of wire do not contribute to the total length of the potentiometer wire since electrical current flows through the copper strips rather than the potentiometer wire in these sections.

- Potentiometer has the advantage that it draws no current from the voltage source being measured. As such it is unaffected by the internal resistance of the source.
- If the graph is non-linear, what conclusion will you draw?

SELF ASSESSMENT

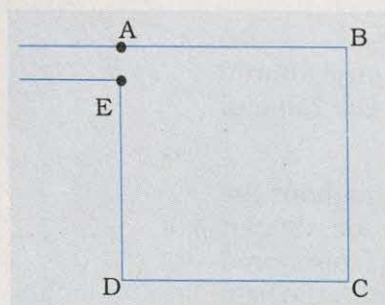


Fig. A 6.2

- A 100 cm wire of homogeneous material and uniform area of cross-section form a square as shown in Fig. A 6.2. How can this arrangement be used to select voltages $1/4$, $1/2$, $3/4$ of the voltage across AE.
- A rheostat R_h used in laboratories along with a key K , battery of emf E and internal resistance r is shown in Fig. A 6.3. R_L is some load resistance that represents an auxiliary circuit which may be there in reality. If D is the midpoint of the wire AB , what would be the voltmeter reading? Does it depend on the value of R_L or R_V , if R_V represents the resistance of the voltmeter? Does it depend on r ?

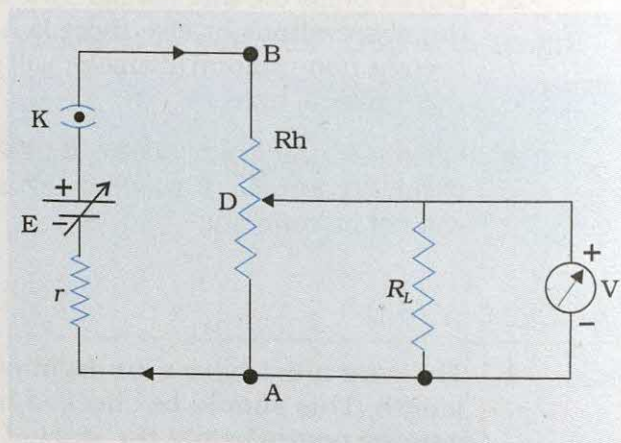


Fig. A 6.3

- Consider a case in the above problem, wherein a potential difference across ends A and B of the wire is 3 V. An experiment requires a potential difference of 1.7 V as precise as possible. Think of the possibilities of reducing emf of the source, using another resistor in series or using a rheostat of the same resistance but of greater length.

Is it possible to get negative potentials using the same circuit? If yes, how?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Connect a circuit as shown in Fig. A 6.3. Record potential difference at various length l from end A. Plot a graph of V versus l . Obtain from the graph the length that corresponds to 1.3 V. Draw a circuit diagram to show how you can supply 1.3 V to an auxiliary circuit that works at 1.3 V.
2. A small circuit called the 'level indicator' (popularly known as dancing LED's) is available in the entertainment electronics market. It is often used in stereophonic two-in-one recorders or graphic equalisers. Connect such a circuit in place of a voltmeter in this activity and estimate the voltage levels at which the LED's in the array glow one after another.

AIM

To study the effect of intensity of light (by varying distance of the source) on a LDR (Light Dependent Resistor).

APPARATUS AND MATERIAL REQUIRED

LDR, two power supplies (12 V each), key, milliammeter (0-500mA), voltmeter (0-10V), a resistance of $47\ \Omega$, a 12 V lamp, connecting wires.

PRINCIPLE

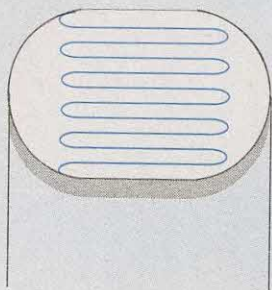


Fig. A 7.1 A Light Dependent Resistance (LDR).

Light dependent resistor or a photoresistor is a device that is sensitive to light. Its resistance varies according to the intensity of light incident on it. It is made from a semiconductor material with light resistors to have light sensitive properties, one such materials is, cadmium sulphide. Snake-like tracks are made of cadmium sulphide on thin metal films [Fig. A 7.1]. LDR has a high resistance due to the fact that majority of electrons are locked into the crystal lattice and not free to move. As light falls on the

lattice, some of the electrons get sufficient energy to break free the crystal lattice to conduct electricity. A typical LDR has a resistance of $1\ \text{M}\Omega$ in total darkness and a few hundred ohm resistance in bright light.

PROCEDURE

1. Assemble the circuit as shown in Fig. A 7.2.
2. First keep the lamp switched off. Plug in the key K.
3. Observe and record voltmeter and milliammeter readings.

4. Calculate the reference measurement of LDR resistance R' .
5. Add this value of resistance to all further measurements. This ensures that background illumination has been taken into account.
6. Set up a 12 V lamp on a fixed stand in vertical position facing LDR. Adjust LDR normally below the lamp at about 10 cm (say).
7. Observe milliammeter and voltmeter readings.
8. Changing the distance between lamp and LDR by 15 cm (say) repeat step 7. Record your observation and calculate resistance of LDR at different distances of the lamp.

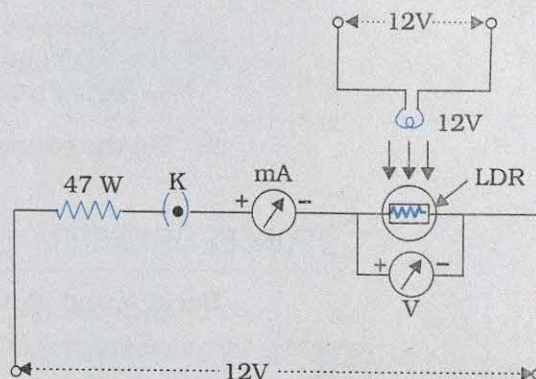


Fig. A 7.2 Circuit to study the effect of intensity of light on an LDR.

OBSERVATIONS AND CALCULATIONS

Range of voltmeter = 0 V to ...V

Least count of voltmeter = ...V

Range of milliammeter = 0 mA to ...mA

Least count of milliammeter = ...mA

Table A 7.1 : Variation in resistance of LDR with distance

Sl. No.	Distance between LDR and the source d cm	Voltmeter Reading V (V)	milliammeter Reading I (mA)	$R = \frac{V}{I} \Omega$	Actual value of resistance $(R + R') \Omega$
1					
2					
...					
5					

RESULT

As distance increases, intensity of incident light decreases and resistance of LDR increases.

PRECAUTIONS

1. LDR is placed normally to the light source so that angle of incidence of light rays remain constant and normal throughout the experiment.
2. All the connections should be made tight.

SOURCES OF ERROR

Background illumination is a source of error in this activity.

DISCUSSION

1. Calculate the product $R.d^2$ in each case. What do you infer?
2. LDRs are used especially in light or dark sensor circuit. It is used in automatic lighting, street light, smoke alarm etc.
3. A suitable resistance is connected in series with LDR to prevent it from damage.

SELF ASSESSMENT

Why does the resistance of LDR not remain constant?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Perform the above activity in totally dark room. Compare and discuss the result with that obtained with normal light in the laboratory.
2. Study the effect of intensity of light on an LDR by using bulbs of different power, keeping the distance same.
3. Provide variable voltage values to power up the light bulb and observe variations in resistance with intensity keeping the distance between LDR and bulb same.
4. Study the effect of intensity of light on LDR of different specifications.

A_{IM}

To identify a diode, a LED, a transistor, an IC, a resistor and a capacitor from a mixed collection of such items.

A_{PPARATUS AND MATERIAL REQUIRED}

Multimeter, a collection of diode, LED, transistor, IC, resistor and capacitor.

P_{RINCIPLE}

A diode is a two terminal device. It conducts when forward biased and does not conduct when reverse biased. It does not emit light while conducting.

A LED (light emitting diode) is also a two terminal device. It conducts when forward biased and does not conduct when reverse biased. It emits light while conducting.

A transistor is a three terminal device. The terminals represent emitter (E), base (B) and collector (C).

An IC (integrated circuit) is a multi-terminal device in the form of a chip. But some may have only three terminals, e.g. 7805, 7806, 7809, 7912.

A resistor is a two terminal device. It conducts equally in both directions.

A capacitor is a two terminal device. It does not conduct but stores some charge when dc voltage is applied.

P_{ROCEDURE}

1. Check the physical appearance of the component.
 - (a) If it has four or more terminals and has the appearance of a chip (black rectangular block), then it is an IC.

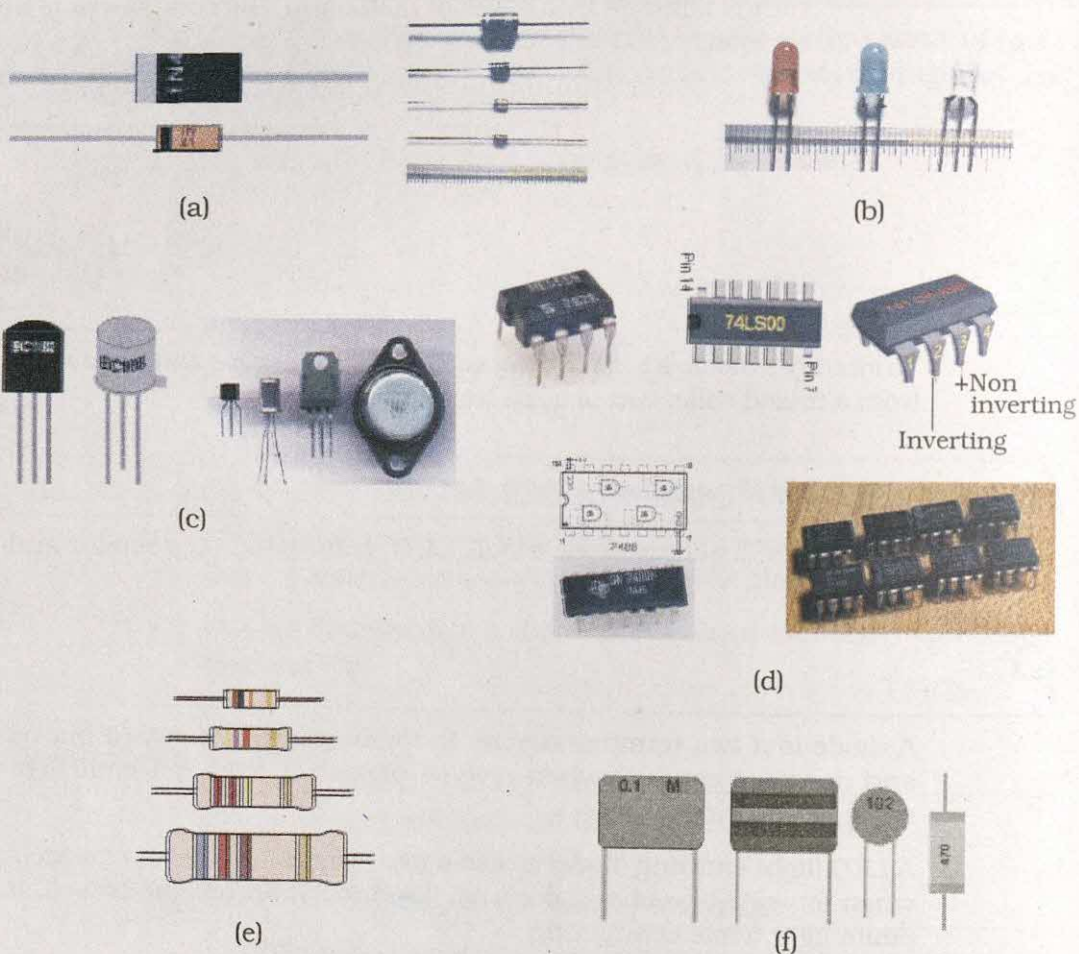


Fig. A 8.1 (a) Diode (b) LED (c) Transistor (d) IC (e) Resistor (f) Capacitor

- (b) If it has three terminals, the component may be a transistor. To confirm, set-up the multimeter in resistance mode (highest range). Connect its black or common terminal to one of the extreme legs of the component and the second terminal (red or positive) to the central leg. Check the multimeter deflection. If a deflection is observed, interchange the multimeter terminals. If no deflection is observed, the component is a transistor. Repeat this test by connecting the multimeter terminals to the central leg and the other extreme leg. If a similar behaviour is observed, the component is a transistor.
- (2) If the component has two terminals, it could be a resistor, a capacitor, a diode or a LED.

- (a) Look for colour bands, if it has a typical set of three colour bands followed by a silver or gold band, the component is a resistor.
- (b) Connect the multimeter terminals (in resistance mode-highest range) to the component terminals and watch for multimeter deflection. Also repeat by reversing the component terminals.
- (c) If the multimeter shows an equal deflection in both the directions, the component is a resistor.
- (d) If the deflection is accompanied with emission of light, in one direction and a much less or zero deflection in the other direction the component is a LED.
- (e) If the multimeter does not show any deflection in one direction and shows deflection with no light emission in the other direction then, the component is a diode.
- (f) If the multimeter does not show any deflection on connecting its terminals either way to the component, it is a capacitor. But if capacitance of capacitor is large, multimeter may show a momentary deflection.
- (g) Record your observations in Table A 8.1 and A 8.2.

Note to teachers

- (i) Avoid giving an IC with three terminals.
- (ii) Preferably use analog multimeter and not the digital multimeter.
- (ii) In case of digital multimeter, the term "deflection" in the instructions may be read as "reading".
- (iii) Label each component by a different alphabet e.g., A, B, C, D, E...

OBSERVATIONS

Table A 8.1 : Checking for the number of terminals

Sl.No.	No. of terminals	Alphabet marked on the device	Name of the Device
1	Two		
2	Three		
3	More than three		

Table A 8.2 : Checking for the state of conduction

Sl.No.	State of conduction	Device Code	Name of the device
1	Conducts in one direction only without any emission of light		
2	Conducts in one direction only with emission of light		
3	Three terminal device; conducts in one direction only between central terminal and either of the remaining two terminals		
4	Conducts in both directions		
5	Does not conduct, gives an initial deflection which decays to zero		

RESULT

A diode, a LED, a transistor, an IC, a resistor and a capacitor are identified respectively from a mixed collection.

PRECAUTION

While obtaining resistance of any component, clean its leads properly.

SOURCES OF ERROR

1. When the metal ends of a multimeter leads are touched, the multimeter should show zero resistance. If it does not show it, bring the pointer to zero using 'Zero Adj knob' on the multimeter. If it is not done, the resistance measurements are not reliable.
2. While checking resistance of a component, avoid touching either of the metal ends of the multimeter leads. Body resistance in parallel with component resistance can affect the resistance measurement.

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

Studies of the basic circuit components such as resistor, capacitor may be undertaken on the following lines:

1. Resistors

Types of resistors

- (a) *Wire wound resistors*: These are made by winding a specified length of wire of some conducting material. The material may be any alloy like mangnnin, constantan, nicrome etc.*
- (b) *Carbon resistors*: They are made of a mixture of graphite (a form of carbon) and a good insulator like shellac in a specified proportion. The mixture is pressed and moulded onto rods by heating. By varying this proportion, carbon resistors are made for a very wide range of values. The stability of such resistors is poor but they are cheap and small.
- (c) *Carbon film resistors***: Carbon resistors are cheap and easily available. A thin film of carbon is deposited onto a small ceramic rod. The resistive coating is spiralled on it to get the desired value of resistance.
- (d) *Thin film resistors*: These are made by depositing a very thin film of a conducting material on some insulating base. The thin film provides a very small cross-sectional area. Hence a large resistance. The films may be made from a metal or an alloy.

Tolerance of a resistor

The actual resistance value of a certain resistor may be different from its specified value. This may be due to external influences like changes in temperature, humidity etc. or due to the inherent limitation in manufacturing a given precise value. Deviations in the resistance value due to later cause is known as tolerance.

Wattage of a resistor

Every resistor has a maximum safe current that it can carry. Currents larger than that will produce excessive heat and may damage it. This is usually not in terms of the current, but in terms of maximum watt of power that can be dissipated in the resistor without causing any damage. It is known as its wattage. Common wattages for carbon resistors are $1/8$, $1/2$, 1 and 2 watts. Higher wattages are also available.

Colour code for resistor

Most common colour code used for resistor consists of three colour bands at one end.

* Wire wound resistors have more undesirable inductance than the other types of resistors.

**See appendix 3 for details.

The colour and their numerical meanings are:

Black - 0	Orange - 3	Blue - 6	White - 9
Brown - 1	Yellow - 4	Violet - 7	
Red - 2	Green - 5	Grey - 8	

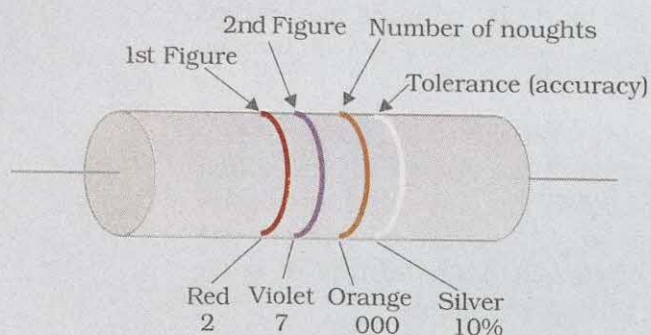


Fig. A 8.2 A carbon resistor with colour code marking

This colour code could be remembered easily by the term BBROY GB VGW (B B ROY Great Britain Very Good Wife). To read the resistance of a colour coded resistor, start with the strip nearest to the end. The colour of the first strip gives the first digit in the resistance value. The colour of the second strip stands for the second digit. The colour of third strip indicates the value of multiplier or the number of zero following second number.

Resistors with only three bands have a tolerance of 20%. Its actual value may vary 20% up or down from its indicated value. If a fourth band is added separated from the first three, then the tolerance of the resistor is known from the colour of the fourth band. If the colour of the fourth band is silver, then tolerance is 10%. Gold colour represents 5% tolerance red represents 2% and brown represents 1%. The ohmic values are often printed on 2% and 1% resistors.

2. Capacitor

Capacitor is a device that stores electrical charge. A capacitor blocks the passage of dc while it allows ac to flow through it.

There are many types of capacitors having different types of dielectrics in general use. These are

- (i) Air capacitor (variable gang capacitors)
- (ii) Mica capacitor (low capacitance)
- (iii) Ceramic capacitor (very low capacitance)
- (iv) Paper capacitor (low capacitance)
- (v) Plastic capacitor
- (vi) Electrolytic capacitor (medium capacitance)
- (vii) Oil filled capacitor (high capacitance)

3. Diode

In some semiconductor junction diodes, a silver ring is shown on one of its end. This end of the diode is n-side and the other end is p-side [Fig. A 8.3(a)]. In some diodes, the symbol of the diode is painted on the body of the diode. The direction of arrow is the direction of current flow. Hence, the side from which the arrow starts is p-side and the side towards which the arrow ends is n-side [Fig. A 8.3 (b)]. Some diodes are bullet shaped in which case the flat side is p-side and the cylindrical side is n-side [Fig. A 8.3 (c)]. In case of a light emitting diode (LED), usually the shorter pin is n-side and the longer pin is p-side [Fig. A 8.3 (d)].

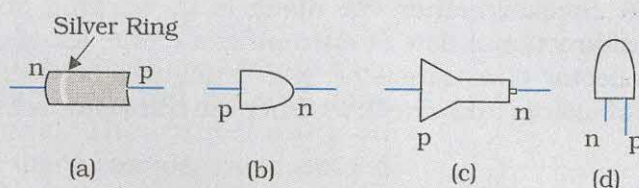


Fig. A 8.3 Shapes of some diodes

4. Transistors

In this activity, a method to distinguish between n-p-n and p-n-p type transistors has been given, provided the pin diagram of the transistor is known. In case, if no pin diagram is known, one can still determine the type (n-p-n or p-n-p) of the given transistor. This can be done by measuring the resistance values between different terminals of the given transistor [(Fig. A 8.4) (a) and (b)]. Table A 9.5 (p.181) summarises the nature of resistance values for n-p-n and p-n-p transistors.

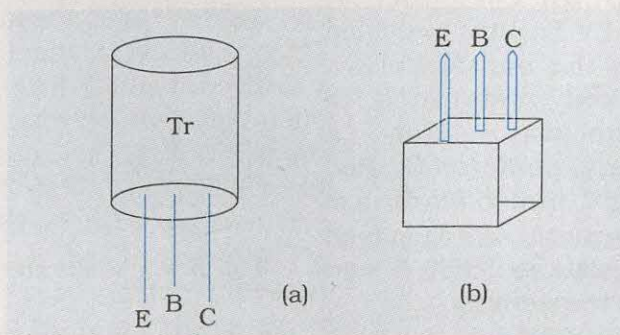


Fig. A 8.4 Different transistor terminals

AIM

Use of Multimeter to

(A) check whether the diode is in working order and to check unidirectional flow of current in a diode; (B) identify emitter, base collector of a transistor; (C) distinguish between n-p-n and p-n-p transistors and check whether the transistor is in working order.

APPARATUS AND MATERIAL REQUIRED

A multimeter, a diode, a transistor (whose base diagram is known), plug key, a battery, resistance box, connecting wires and sand paper.

PRINCIPLE

Analog multimeter used in resistance mode

In this selection a circuit with a battery and resistors come into play. The circuit diagram below (Fig. A 9.1) indicates the main circuit components; a 3V battery (provided in the multimeter), a fixed resistance, a rheostat and a galvanometer G. Red and black leads are connected at fixed resistance ends B and A respectively.

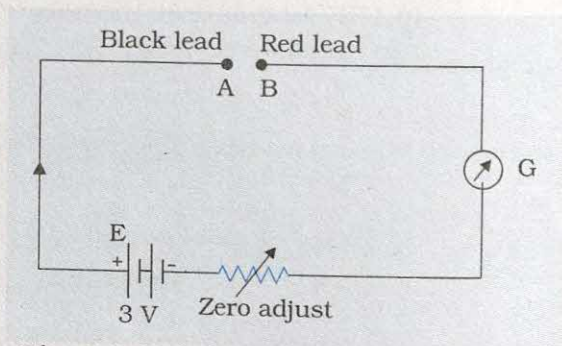


Fig. A 9.1 Multimeter in resistance mode

The deflection is adjusted to full scale deflection (zero mark on the scale), using the rheostat (zero adjust) by first shorting the red and black leads. Any resistance which has to be tested/evaluated is placed between A and B. The deflection due to current in the circuit is calibrated to read the resistance.

You will notice that the black lead is actually connected to the positive and red to the negative of the internal 3 V battery. While measuring values of resistances, it is immaterial how they are connected across A and B. However, it becomes important when this battery also provides the bias for a diode or a transistor junction.

(A) Checking whether a diode is in working order and to check unidirectional flow of electric current through it

A semiconductor junction diode, when connected (or biased) in the forward direction, offers a low resistance. However, when it is biased in the reverse direction, it offers a very high resistance. Therefore, the working of a junction diode can be examined by measuring its resistance in the forward and reverse bias conditions. The functioning of junction diode can also be examined by checking the unidirectional flow of current in a circuit as shown in Fig. A 9.2. For a diode in proper working order, a substantial current (of the order of few mA) will flow in the forward bias condition. If the polarity of the bias is reversed (i.e., diode in reverse bias condition), negligible current (of the order of few μA) will flow.

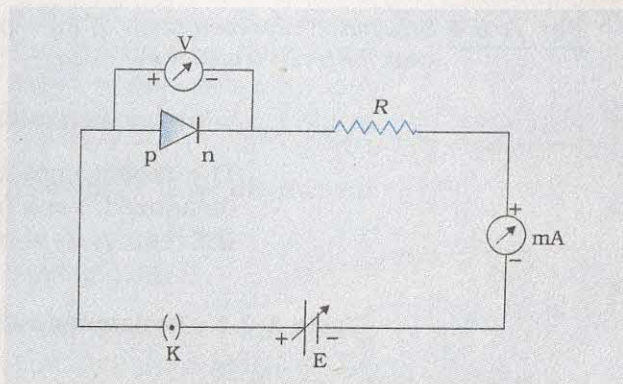


Fig. A 9.2 A semiconductor junction diode in the forward bias

(B) Identification of emitter, base and collector of a transistor

In general, each transistor has three pins of the same size. In some transistors a dot or mark is put on the body near one of the pins. This pin is the emitter. The Emitter (E), Base (B) and Collector (C) of a transistor can be identified using its pin diagram. Fig. A 9.3 shows the base diagram of a typical metal capped cylindrical transistor. This has been drawn by keeping the pins of transistor pointing upwards. In fact, there is no universal pin diagram for the transistors. One can find the pin diagram of a given transistor (transistors have code numbers AC 127, BC548, 2N3055HL 100 etc.) in most transistor manuals.

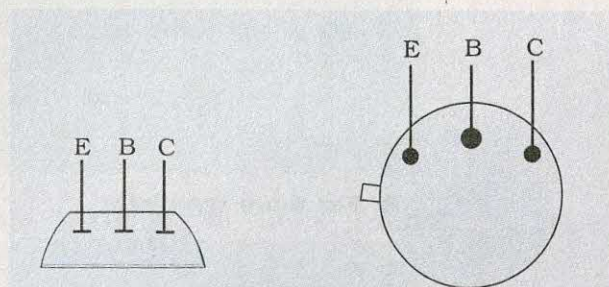


Fig. A 9.3 Base diagram of a typical metal-capped cylindrical transistor. Note that the pin connections may be different for different transistors. It is advisable to refer to the manufacturer's data sheet.

(C) Distinguishing between n-p-n and p-n-p transistors and checking whether the given transistor (p-n-p or n-p-n) is in working order

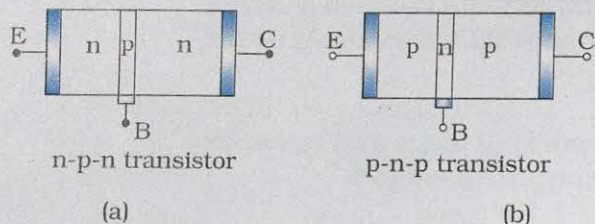


Fig. A 9.4 Schematic representation of (a) n-p-n, and (b) p-n-p transistors

The base B of an n-p-n transistor is p-type material whereas emitter E and collector C are of n-type materials (Fig. A 9.4 a). Therefore, the forward resistance between the base B and the emitter E (or collector C) should have a low value. In case of a p-n-p transistor (Fig. A 9.4 (b) (whose emitter E, base B, and collector C are p-, n- and p-type materials respectively), the forward resistance between the emitter and base should be low.

The resistances between the base-emitter, and base-collector are measured. For a transistor in working order, resistance values follow the results as shown in Table A 9.1.

Table A 9.1 : Resistance values between different terminals of n-p-n and p-n-p transistors

Sl.No.	One of the transistor terminals (B, C or E) connected to negative lead (black) of the multimeter	Transistor terminal connected with positive (red) lead of the multimeter	Bias	Resistance
--------	--	--	------	------------

A. For n-p-n transistor

1	E	B	Forward	Low
2	C	B	Forward	Low
3	B	C	Reverse	Very high
4	B	E	Reverse	Very high

B. For p-n-p transistor

1	B	E	Forward	Low
2	B	C	Forward	Low
3	E	B	Reverse	Very high
4	C	B	Reverse	Very high

Any deviation from the results shown in Table A 9.1 would indicate that the given transistor is not in working order. For example, for an p-n-p transistor, a low resistance value between terminal E (when connected with the negative lead of the multimeter) and terminal B (when connected with positive lead of the multimeter) indicates that the diode's terminals E and B are short-circuited. For a working transistor, it should have shown very high resistance, being reverse biased.

PROCEDURE

1. The diodes, transistors, and connecting wires may have some insulating layers on their surface if they are not used for a long time. Therefore, clean their ends using a sand paper till they shine.

(A) Diode in working order and unidirectional flow of current in a diode

2. Set the multimeter in resistance measuring mode.
3. Connect the diode terminal 1 with the positive lead of the multimeter and terminal 2 with the negative lead of the multimeter. Measure the diode resistance. Reverse the diode connections and again measure the diode resistance. Record your observations in Table A 9.2. Also conclude whether the given diode is in working order or not.

Note: A low value of diode resistance (ranging from few Ω to $k\Omega$) indicates that the diode is connected in forward bias. While a very high value of resistance (of the order of $M\Omega$), indicates that the diode is connected in reverse bias.

If both the resistance values, i.e., in reverse and forward directions, are low then it means that the diode is short-circuited. On the other hand if both the resistance values are very high, then the diode junction may be considered as discontinuous or open. Thus, in both the conditions, the diode condition may be concluded as not in working order.

4. Identify the p-and n-terminals of the given diode from the observations.
5. Connect the diode with the cell and resistance box in a series circuit (without key ON) as shown in Fig. A 9.2. Set the multimeter in current measuring mode at a suitable range (mA, start from high current range).
6. Take out a suitable resistance R from the resistance box in the circuit to restrict the current within the current range chosen (in the multimeter). Put the key ON and measure the current flowing through the circuit. Record your observations in Table A 9.3.

7. Repeat step 6 for a few more values of resistance R in the circuit.
8. Reverse the polarity of diode (now the diode is reverse biased) and repeat steps 6 and 7.

(B) and (C) Identifying n-p-n and p-n-p transistors and checking whether the given transistor (p-n-p or n-p-n) is in working order

9. Identify the emitter E, base B, and collector C of the given transistor by observing dot or a mark on the body of transistor near one of its pins. Draw the base and schematic diagrams of the given transistor in your notebook.
10. Set the multimeter in 'resistance measuring mode'.
11. Connect the positive (red) lead of the multimeter with the base and negative led (black) with emitter (or collector) terminal and measure the resistance. Record the observations in Table A 9.4.
12. Reverse the connections of the multimeter and again measure the resistance values between the transistor's base B and emitter E (or collector C) terminals. Record observations in Table A 9.4.
13. From Table A 9.4, check whether the given transistor is in working order or not.
14. For a transistor that is in working order, using the information given in Table A 9.1, infer the nature of the given transistor (n-p-n or p-n-p).

OBSERVATIONS

1. Table A 9.2 : Measurement of diode resistance

Sl. No.	Diode terminal connected with the positive lead of the multimeter	Diode terminal connected with the negative lead of the multimeter	Resistance (Ω)
1	1	2	
2	2	1	

2. Table A 9.3 : Unidirectional flow of current through a diode

(a) When diode is connected in forward bias

Sl. No.	Resistance (Ω)	Current (mA)
1		
2		

(b) When diode is connected in reverse bias

Sl. No.	Resistance (Ω)	Current (mA)
1		
2		
3		

3. Table A 9.4: Resistance values between different transistor terminals

Sl. No.	Transistor terminal connected with the positive lead of the multimeter	Transistor terminal connected with the negative lead of the multimeter	Resistance (Ω)
1	B	E	
2	B	C	
3	E	B	
4	C	B	

RESULT

1. The p- and n-sides of the given diode are identified from Table A 9.2.
2. The given diode is/is not in working order (from Tables A 9.2 and A 9.3)
3. The unidirectional flow of current in a diode has/has not been realised (from Table A 9.3).
4. The three terminals of the given transistor have been identified and the pin diagram has been shown in Fig. A 9.3.
5. The given transistor is n-p-n/p-n-p (from Table A 9.4).
6. The given transistor is/is not in working order (from Table A 9.4).

PRECAUTIONS

1. While obtaining resistance of any component, clean its leads properly.
2. Use the selector switch of the multimeter carefully for various measuring modes.

SOURCES OF ERROR

1. When the metal ends of multimeter leads are touched, the multimeter should show zero resistance. If it does not show this, bring the pointer to zero using 'zero Adj knob' on the multimeter. If it is not done, the resistance measurements are not reliable.
2. While checking resistance of a component, avoid touching both the metal ends of the multimeter leads. Body resistance in parallel with component resistance can affect the resistance measurement.

DISCUSSION

1. In a transistor, the junction joining the base region and the emitter region is called base-emitter junction. The junction joining the base region and the collector region is called base-collector region.
2. When multimeter is in current measuring mode, shunt resistance of different values are introduced in the circuit paralleled with the coil. In voltage measuring mode resistances of different values come in contact with the circuit in series with the coil. When you select the switch of the multimeter for measurement of resistance, different resistances are introduced in circuit in series with the coil of the multimeter.

SELF ASSESSMENT

Find the base of a transistor if pin diagram is not available. You may use the Table A 9.5 for this purpose.

Using the results given in Table A 9.5, it can be determined whether the given transistor is n-p-n or p-n-p type.

Table A 9.5 : Nature of resistance values between different transistor terminals (when pin diagram is not known)

(Note: Here terminal 2 is assumed as the base pin of transistor)

Sl. No.	Transistor terminal connected with the positive lead of the multimeter	Transistor terminal connected with the negative lead of the multimeter	Nature of resistance
---------	--	--	----------------------

A. For n-p-n transistor

1	1	2	Very high
2	1	3	Very high
3	2	1	Low
4	2	3	Low
5	3	1	Very high
6	3	2	Very high

B. For p-n-p transistor

1	1	2	Low
2	2	1	Very high
3	1	3	Very high
4	3	1	Very high
5	2	3	Very high
6	3	2	Low

A_{IM}

To observe refraction and lateral deviation of a beam of light incident obliquely on a glass slab.

A_{PPARATUS AND MATERIAL REQUIRED}

Drawing board, rectangular glass slab, white sheet of paper, adhesive tape (cello-tape), drawing pins, a metre scale, alpins, protractor, sharp pencil and eraser.

P_{RINCIPLE}

When a ray of light is incident on a rectangular glass slab, it is refracted through it. It emerges out of the slab parallel to the direction of the incident ray. The emergent ray suffers only a lateral displacement. For a given angle of incidence and a pair of media, the lateral deviation is proportional to the thickness of the glass slab.

P_{ROCEDURE}

1. Fix a white sheet of paper on the drawing board with the help of cello-tape or drawing pins.
2. Place the glass slab lengthwise symmetrically at the centre of the paper sheet and mark its boundary ABCD (Fig. A10.1) on the paper sheet with a sharp pencil.
3. Draw a normal at a point F on the face AB. Draw a line EF, representing the incident ray, making an angle i the angle of incidence with the normal.
4. Fix two alpins P and Q with sharp tips, about 8 to 10 cm apart, vertically on the line EF.
5. Observe the images of the two pins through the face opposite of the glass slab. Fix two more alpins R and S

about 8 to 10 cm apart, vertically on the white paper sheet carefully with their tips in line with the tips of the images of P and Q. Take care that the tips of all the alpins appear to be on a straight line.

6. Remove the glass slab and mark the pin prick positions of the alpins on the white paper sheet with a pencil. Draw a straight line GH, representing the emergent ray, passing through the points marked R and S, meeting the face CD at G.
7. Draw the line FG to represent the refracted ray. Draw a normal at the point G on the face CD; making an angle of emergence e with the normal. Measure the angle of incidence i and angle of emergence e with a protractor. Write the values of these angles on the white paper sheet. Do you find some relation between $\angle i$ and $\angle e$?
8. Extrapolate EF forward to meet the face CD of the glass slab at O. Draw the perpendicular OL to the line GH.
9. Check if the emergent ray GH is parallel to the incident ray EF along the original direction. It is laterally deviated by a perpendicular distance OL. Measure the lateral deviation $OL = d$ and also the thickness of the glass slab.
10. Repeat steps 2 to 9 by changing the angle of incidence.
11. Repeat the steps 2 to 10 by using glass slabs of different thickness. Measure the lateral deviation and the thickness of the glass slab each time. Also write the values of $\angle i$ and $\angle e$ on the white paper sheet each time.
12. Record observations in tabular form with proper units. What inference do you draw from your observations?

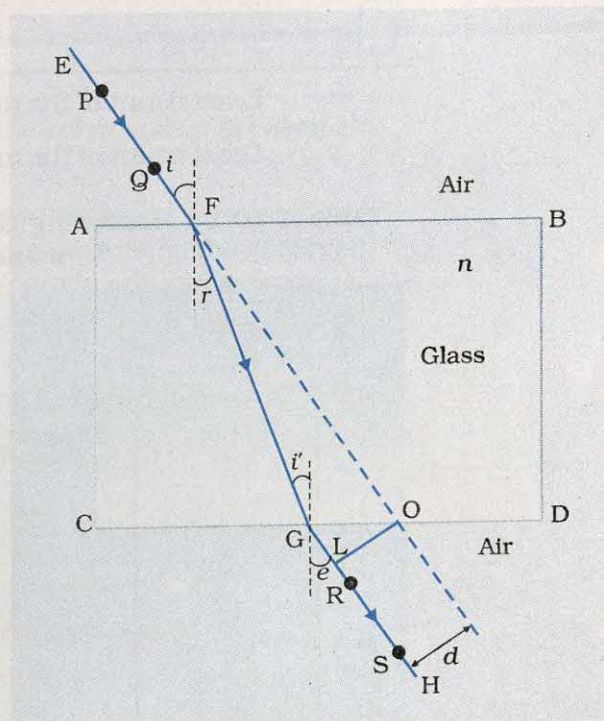


Fig. A10.1 Refraction through a rectangular glass slab

OBSERVATIONS

Least count of the protractor = ... (degree)

Least count of the metre scale = ... mm = ... cm

Table A 10.1 : Measuring the angle of incidence i , angle of emergence e and lateral deviation d .

Sl. No.	Thickness of the Glass slab, $t \times 10^{-2}$ m	Angle of incidence i		Angle of emergence e		Lateral deviation $d \times 10^{-2}$ m
		(degree)	(radians)	(degree)	(radians)	
1	t_1					
2	t_1					
--	--					
5	t_1					
6	t_2					
--	--					
10	t_2					
11	t_3					
--	--					

RESULT

1. The ray of light emerging from a glass slab is parallel to the incident ray direction, but is laterally deviated.
2. The lateral deviation of the emergent ray with respect to the incident ray is directly proportional to the thickness of the glass slab.

DISCUSSION

1. The accuracy in the measurement of angles of incidence i and emergence e and the lateral deviation d depends on how sharp the pin tips are, and how careful you are in observing the tips of the pins to lie along the same straight line. Take special care in observing the tips of the pins, marking the pin pricks, drawing the incident, refracted and emergent rays with a sharp pencil, and measuring the angles i and e , accurately with a protractor.

SELF ASSESSMENT

1. Examine Table 10.1 and interpret the relationship between $\angle i$ and $\angle e$, and between t and d .
2. Plot a graph between lateral deviation d along the y-axis and thickness t of the glass slab along the x-axis using the observed values from Table 10.1 keeping the angle of incidence same. Identify the shape of the graph you have obtained and interpret it.

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. From the observations with the glass slab placed lengthwise, breadthwise and thicknesswise, find out the refractive index of the material (glass) of the slab. Discuss your result.

[Hint: Use $\sin i / \sin r = n$ (refractive index of the material)]

2. Measure the angle i' in each case of the above observations. Calculate the

ratio $\left(\frac{\sin i'}{\sin e} \right) = n'$. What is the relation between $\angle r$ and $\angle i'$ and also between

$\angle i$ and $\angle e$? Compare the ratio n' with $\left(\frac{\sin i}{\sin r} \right) = n$. Remember that the ray

FG is the incident ray on face CD and GH is the refracted ray. Discuss the relation between n and n' .

AIM

To observe polarisation of light using two polaroids.

APPARATUS AND MATERIAL REQUIRED

Two polaroid sheets, source of light/sunlight, card board, a pair of scissors, white paper, glue.

TERMS AND DEFINITIONS

A light wave consists of a varying electric field vector $\mathbf{E}$ and a varying magnetic field vector $\mathbf{B}$, which are perpendicular to each other. Each of these field vectors are also perpendicular to the direction of propagation of the wave.

- (i) *Unpolarised light*: The orientation of electric vector is not confined to one direction only but in all directions randomly, transverse to the direction of propagation.
- (ii) *Plane or linear polarisation*: Light waves are said to be plane/linearly polarised if the electric field vector $\mathbf{E}$ is restricted to one direction in a plane normal to the direction of propagation.
- (iii) *Polaroid*: A polaroid consists of long chain molecules aligned in a particular direction. The electric vectors (associated with the propagating light wave) along the direction of the aligned molecules get absorbed. Thus, if an unpolarised light wave is incident on such a polaroid, then the light wave will get linearly polarised with the electric vector oscillating along a direction perpendicular to the aligned molecules. This direction is known as the *pass-axis* of the polaroid.

Plastic sheets of synthetic substances are commonly used in sun glasses, calculator and digital watch.

- (iv) *Polariser and analyser*: When the passage of light through two polaroids is studied, the transmitted fraction of intensity falls between 1 to 0 as the angle between the axis of their transmission varies from 0 to 90. The first polaroid next to the

source being used is called the polariser and the second polaroid used is called analyser.

PRINCIPLE

Natural light is associated with electric vectors normal to the direction of propagation and lying in all possible planes passing through the light beam. However, all these vectors can be resolved along two mutually perpendicular directions.

Every polaroid has an axis of transmission such that when the polaroid is placed normal to the path of an unpolarised light beam, the component of electric vector associated with it and parallel to the axis of transmission is allowed to pass through and the transmitted light is plane polarised. This can be checked by rotating another polaroid placed next to the first polaroid along the beam of light, (Fig. A 11.1) a position comes for which the transmitted intensity vanishes. This position corresponds to the situation when the axis of transmission of the two polaroids are perpendicular to each other. When these axes are parallel to each other, the transmitted intensity attains a maximum value. Hence, the fractional intensity ranges between 0 and 1 as the two polaroids in the path of light beam are rotated with respect to each other.

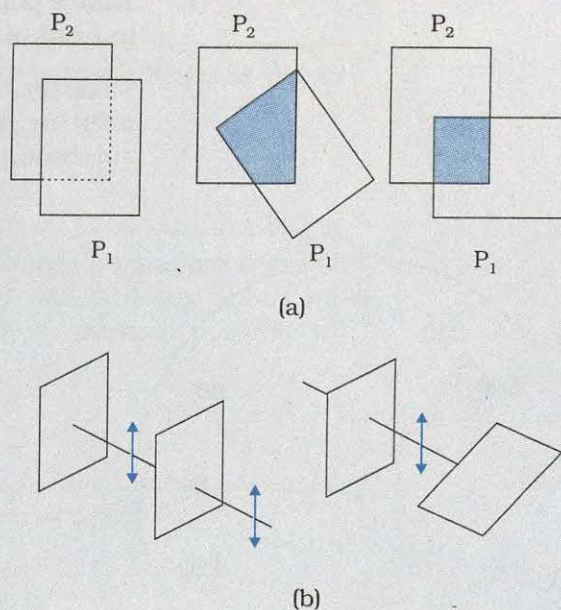


Fig. A 11.1 (a) Passage of light through two polaroids P_2 and P_1 . The transmitted fraction falls from 1 to 0 as the angle between them varies from 0° to 90° . Notice that the light seen through a single polaroid P_1 does not vary with angle. (b) Behaviour of the electric vector when light passes through two polaroids. The transmitted polarisation is the component parallel to the polaroid axis. The double arrows show the oscillations of the electric vector.

PROCEDURE

(a) Making a circular scale for angle measurement

1. Take a card board. Paste a white paper on it. Draw a circle of radius 10 cm on the white paper.
2. Cut the circle with a pair of scissors.

3. Mark angular divisions on the circle as shown in (Fig. A 11.2).
4. Cut a hole at the centre of the circle such that your polariser fits in the hole. Attach the polaroid in the hole (Fig. A 11.3).
5. Prepare a similar scale for analyser.

(b) Observing Polarisation

1. Take a polaroid piece P_1 (also known as polariser) and hold it in front of your eye and observe light from any source.
2. Take the other polaroid (also known as analyser) and put it over the first polaroid P_1 and observe the light through the combined system.

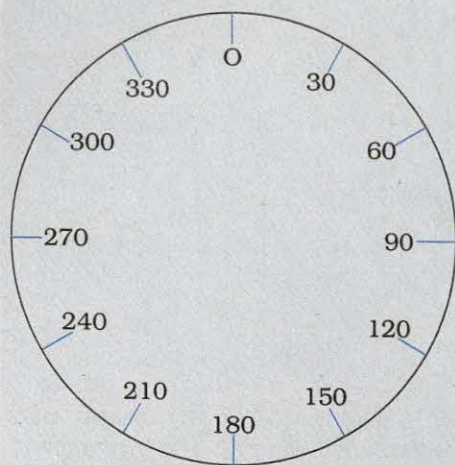


Fig. A 11.2 Circle with angular division

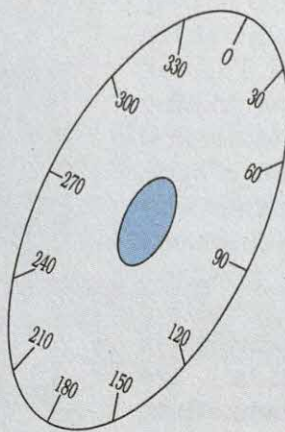
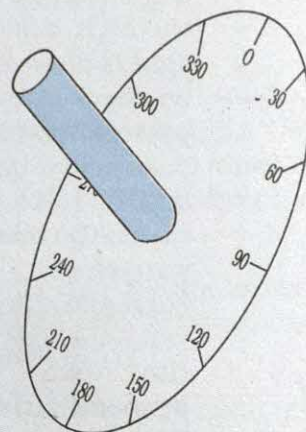


Fig. A 11.3 Circular scale for angle measurement



3. Rotate analyser to get maximum intensity of emerging light. Note down the difference between scale readings.
4. Now rotate the analyser so that you get zero intensity of emerging light. Note down the difference between scale readings.

OBSERVATIONS

1. Difference between scale readings for maximum intensity,
 $a = \dots^\circ$.
2. Difference between scale readings for minimum intensity,
 $b = \dots^\circ$.

3. Rotation of analyser from maximum intensity to minimum intensity
 $a - b = \dots^\circ$

RESULT

The angle through which the intensity changes from maximum to minimum = $\dots^\circ$

PRECAUTION

Care should be taken to handle the polaroids carefully so as not to leave finger prints.

DISCUSSION

While observing light from some source through a polariser there is no change in the intensity of light. What can you say about its polarisation condition? How does an analyser make it possible to detect polarisation condition?

SELF ASSESSMENT

1. What do you understand by polarisation of light?
2. Can sound waves be polarised?
3. Name the crystals commonly used for polarising light.
4. Name a source of light which directly gives plane polarised light.
5. Study polarisation of sunlight by different methods (polarisation by scattering, reflection).

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Take a photodiode for light intensity measurement. Connect it properly with a multimeter so that it glows. By rotating the analyser through different angles, note down the variations in transmitted intensity. Plot appropriate graph to verify Malus law, $I = I_0 \cos^2 \theta$ where I_0 is the intensity of light at $\theta = 0^\circ$ and I is the intensity of light at an angle θ .
2. Give a write up to show how this activity can be used to demonstrate transverse nature of light?

AIM

To observe diffraction of light due to a thin slit.

APPARATUS AND MATERIAL REQUIRED

Two razor blades, one adhesive tape/cello-tape, source of light (electric bulb/ laser pencil), a piece of black paper, two glass slides.

PRINCIPLE

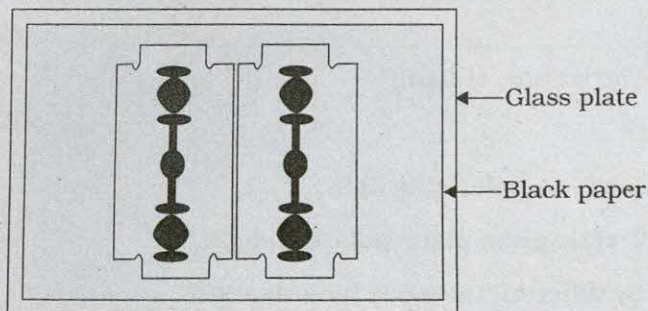


Fig. A 12.1 A fine slit made by using two razor blades, one glass slide and a piece of black paper.

When a beam of light passes through a fine opening (aperture) or around a sharp obstacle, it bends around corners of the obstacle/aperture. The light beam spreads and penetrates into the geometrical shadow of the obstacle. This phenomenon of bending of light around fine openings/obstacles is called diffraction and is one of the evidences in favour of wave nature of light. It arises because of the interference of light waves from different points of the same wave front. Two razor blades with their sharp edges held parallel, quite close to each

other (separation being of the order of wavelength of light λ) form a fine single slit (Fig. A 12.1). The diffraction pattern due to a single slit consists of a central bright band, surrounded on both sides by coloured bands (with electric bulb) and alternate dark and bright bands (with laser pencil) of decreasing intensity and fringe width.

PROCEDURE

1. Make a fine, single slit using razor blades. For this purpose, take a glass plate and fix a black paper on top of it. Cut out a narrow slit in the central part of the black paper. Place two razor blades, side by side, quite close to each other over this slit as shown in Fig. A 12.1.

2. Place a glowing clear electric lamp preferably with a straight filament (or a laser pencil) at sufficient distance (about 4 to 8m) behind the fine slit between the two sharp edges of the razor blades. Observe the lamp through the slit. What do you find?
3. Alternatively, place the slit about 0.5m from the wall and the source of light at a distance of about 15-20 cm behind the slit. Observe the light falling on the wall.
4. Repeat the observations of steps 2 and 3 with a laser pencil. Note the changes you observe.

RESULT

Light waves incident on very fine apertures (openings) bend around corners and exhibit phenomenon of diffraction.

DISCUSSION

1. The sharpness of diffraction fringes depends mainly on the extreme fineness of the slit, made using razor blades, keeping them quite close to each other.
2. Monochromatic light from a laser pencil is preferred over ordinary electric bulb for obtaining better effect on the screen.

With ordinary light (an electric bulb) not many fringes are observed clearly, while with a monochromatic source (laser pencil) a large number of distinct bright and dark fringes are observed for a reasonable width of the slit.

SELF ASSESSMENT

1. Hold two razor blades side by side so that nearer sharp edges are parallel and quite close to each other. The two edges are often not parallel to each other when held like this. Do you expect the bands to become wider and/or closely spaced at a point/part of the slit where the separation of the edges is less? Do you find bands having some colours? Interpret your observations.

[Hint: The position of all the bands, except the central band, depends on wavelength and they will show some colours. Use of a filter for red or blue will make the bands/fringes clearer. You can easily observe wider bands/fringes by using a red filter compared to that by using a blue filter.

2. The diffraction pattern is observed for slit widths of the order of wavelength λ of light used. Observe what happens when the slit width is few times λ . Interpret the reason.

A_{IM}

To study the nature and size of the image formed by (i) a convex lens (ii) a concave mirror on a screen by using a candle and a screen (for different distances of the candle from the lens/mirror).

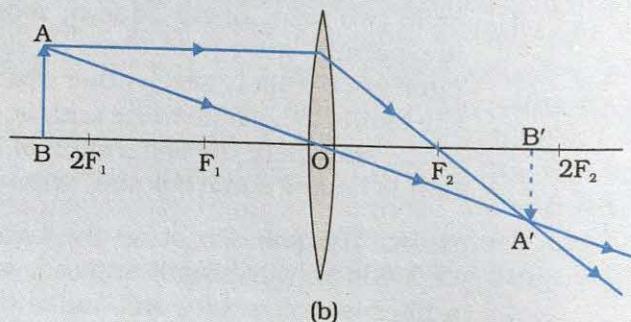
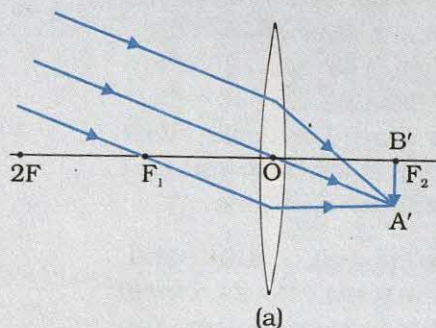
- (i) **To study nature and the size of the image formed by a convex lens. (for different distances of the candle from the lens)**

A_{PPARATUS AND MATERIAL REQUIRED}

A candle, match box, a small candle-stand, a convex lens of small focal length and known thickness, a screen with a stand, metre scale.

P_{RINCIPLE}

The position, nature and size of the image of an object formed by a thin convex lens varies with the change in the position of the object as illustrated in Fig. A 13 (i).1(a) to A 13 (i).1(f) for some specific positions. It is assumed that both the spherical surfaces of the lens have same radii of curvature.



- (a) Object is at infinity, i.e., $u = \infty$. A real, inverted and highly diminished image is formed at the second principal focus, F₂ on the other side of the lens, i.e. $v = f$, (i) when incident rays of light is parallel to the principal axis; and (ii) when incident rays of light are not parallel to

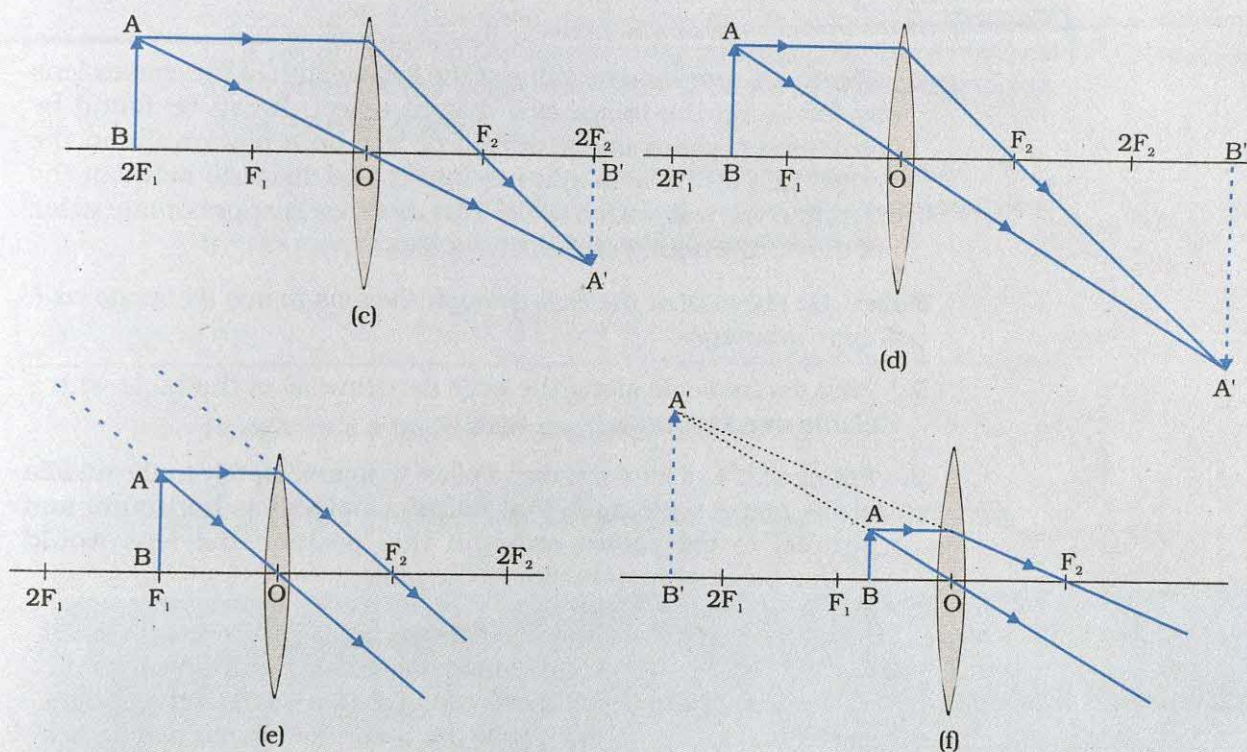


Fig. A 13 (i). 1 (a), (b), (c), (d), (e), (f) The position, size and nature of the image $A'B'$ formed by a thin convex lens LL' for different positions of the object AB .

the principal axis, the image is formed on the principal axis and focal plane respectively.

- (b) Object is in between infinity and $2F_1$, i.e., $\infty > u > 2f$. A real, inverted and diminished image lies in between second principal focus F_2 and $2F_2$ on the other side of the lens, i.e., $2f > v > f$.
- (c) Object is at $2F_1$, i.e., $u = 2f$. A real and inverted image is also formed at $2F_2$ on the other side of the lens, i.e., $v = 2f$. The size of the image is equal to the size of object.
- (d) Object is in between $2F_1$ and first principal focus F_1 , i.e., $2f > u > f$. A real, inverted and enlarged image is formed in between $2F_2$ and infinity on the other side of the lens, i.e., $2f < v < \infty$.
- (e) Object is at the first principal focus, i.e., $u = f$. A highly enlarged, real and inverted image is formed at infinity on the other side of the lens, i.e., $v = \infty$.
- (f) Object is in between the principal focus and the optical centre O of the lens, i.e., $f > u > 0$. An enlarged, virtual and erect image is formed on the same side of the object.

PROCEDURE

1. Obtain an approximate value of the focal length of the convex lens by focussing the image of a distant object. It can be found by obtaining a sharp image of Sun or tree on a plain wall, on the other side of the lens and measuring the distance between the lens and the wall with a scale. This distance is approximate value of the focal length, f of the convex lens.

Note: Do not look at the Sun through the lens to see its image as it will hurt your eyes.

2. Fix a metre scale along the edge (lengthwise) of the table with a clamp or a cello tape.
3. Fix lens LL' in a lens stand and place it approximately in the middle of the metre scale such that its principal axis is horizontal and parallel to the metre scale. In this position the lens would lie in a plane perpendicular to the table.

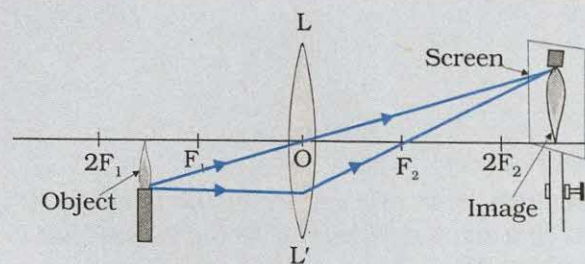


Fig. A 13 (i). 2 Real images of a lighted candle formed by a thin convex lens.

4. Mount a lighted candle vertically on a small candlestand. Place this candlestand on the left hand side of the lens. Adjust the upright such that the tip of the lighted candle lies on the principal axis of the lens. In this situation, the height of the tip of the flame of lighted candle becomes equal to the height of the optical centre of the lens.

5. Shift the candlestand (from left side of the lens) to a point slightly away from $2F_1$ (i.e., to a distance slightly more than $2f$ from the point O, where f is the focal length of the lens as determined in step 1). According to Fig. A13 (i).1(b), the image of candle will be formed at a position closer to the second principal focus F_2 on the right hand side of the lens.
6. Place a vertically mounted screen on the right hand side of the lens. Adjust its height such that most of its portion lies above the principal axis of the lens.
7. Shift the position of the screen near to the second principal focus F_2 on the metre scale functioning as an optical bench.
8. Make final adjustments to get a sharp image of the lighted candle on the screen. Note the nature of the image.
9. Measure the height of the flame of the lighted candle using a small plane mirror strip with a graph paper strip pasted on it. Also

measure the height of the image of the flame being formed on the screen. For this, fix a small graph paper on the screen. Alternatively, fix a white paper on the screen and mark the positions of the top and bottom of the image and determine the height of the image using a metre scale.

10. Shift the lighted candle towards the lens by a small distance (say by 5 cm or 3 cm). Repeat steps (8) and (9) and record observations. In this manner take at least six sets of observations.

OBSERVATIONS

1. Rough focal length of the convex lens = ...cm

Table A 13 (i) 1 : Nature, size and position of image with different positions of object

Sl. No.	Position of lens (cm)	Position of candle (cm)	Size of flame (cm)	Position of image on the screen (cm)	Size of image (cm)	Nature of image (cm)	Relative size of image (cm)
1							
2							
...							
6							

RESULT

1. As the object moves towards the focus of the lens the size of the image increases and it moves away from the focus. In all these positions image is real and inverted and is formed on the other side of the lens.
2. When the object is brought too close to the lens, the image on the other side is not seen.
3. When the object is at a distance less than the focal length, the image formed is virtual, enlarged and erect. It is formed on the same side of the lens as that of the object.

P RECAUTIONS

1. This experiment should be performed at a shaded place where no direct light reaches (preferably in a dark room) otherwise the images may not be distinctly visible.
2. While estimating the rough value of focal length f of the lens by focusing the Sun, do not look at the image directly as it may hurt your eyes.
3. The uprights supporting the optical elements should be rigid and mounted vertically.
4. The aperture of the lens should be small otherwise the image formed will not be distinct.
5. Eye should be placed at a distance more than 25 cm from the image formed on the screen.

D ISCUSSION

1. If the object is placed between the optical centre and focus, the image so formed will be virtual in nature, you will not get this image on the screen. Draw the ray diagram.
2. When the candle is placed near the focus, the image is formed at infinity. It may go beyond the end of the table.

S ELF ASSESSMENT

1. How does the size of your image formed by a convex lens vary as you move from the other end of the table towards the lens?
2. Where should the object be placed to get a virtual and erect image of the object?
3. What should be the position of the object to get an image on the same side of the lens as the object?
4. How does the position of the image formed by a convex lens vary as you move along the principal axis of the lens from infinity to its focus?
5. What will be the position of the object to get a real image having the same size as the object?

AIM

- (ii) To study the nature and size of the image formed by a concave mirror on a screen by using a candle and a screen (for different distances of the candle from the mirror).

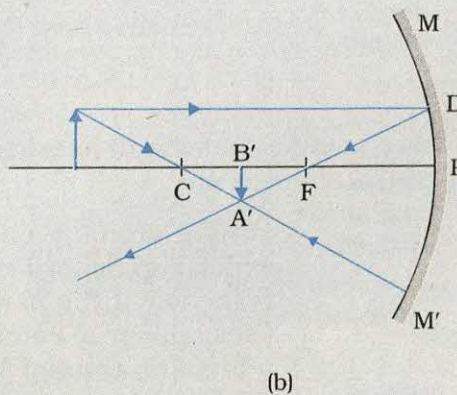
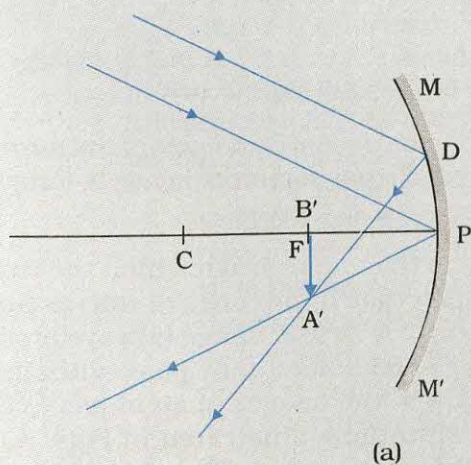
APPARATUS AND MATERIAL REQUIRED

An optical bench, candle, match box, a small candlestand, concave mirror of nearly 25 cm focal length, a screen, three uprights (with clamps), metre scale, adhesive tape and spirit level.

PRINCIPLE

The position, nature and size of the image of an object formed by a concave mirror changes with the position of the object. Figs. A13(ii). 1 (a) to (f), show the image formation by placing the object at different positions in front of the mirror in different situations.

- Object is at infinity, i.e., $u = \infty$. A real, inverted and highly diminished image is formed at the principal focus, i.e., $v = f$.
- Object is in between infinity and the centre of curvature, i.e., $\infty > u > 2f$. A real, inverted and diminished image lies in between C, the centre of curvature and principal focus, F, i.e., $f < v < 2f$.
- Object is at centre of curvature, i.e., $u = 2f$. A real and inverted image is formed at the centre of curvature, i.e., $v = 2f$. The size of the image is equal to the size of object.



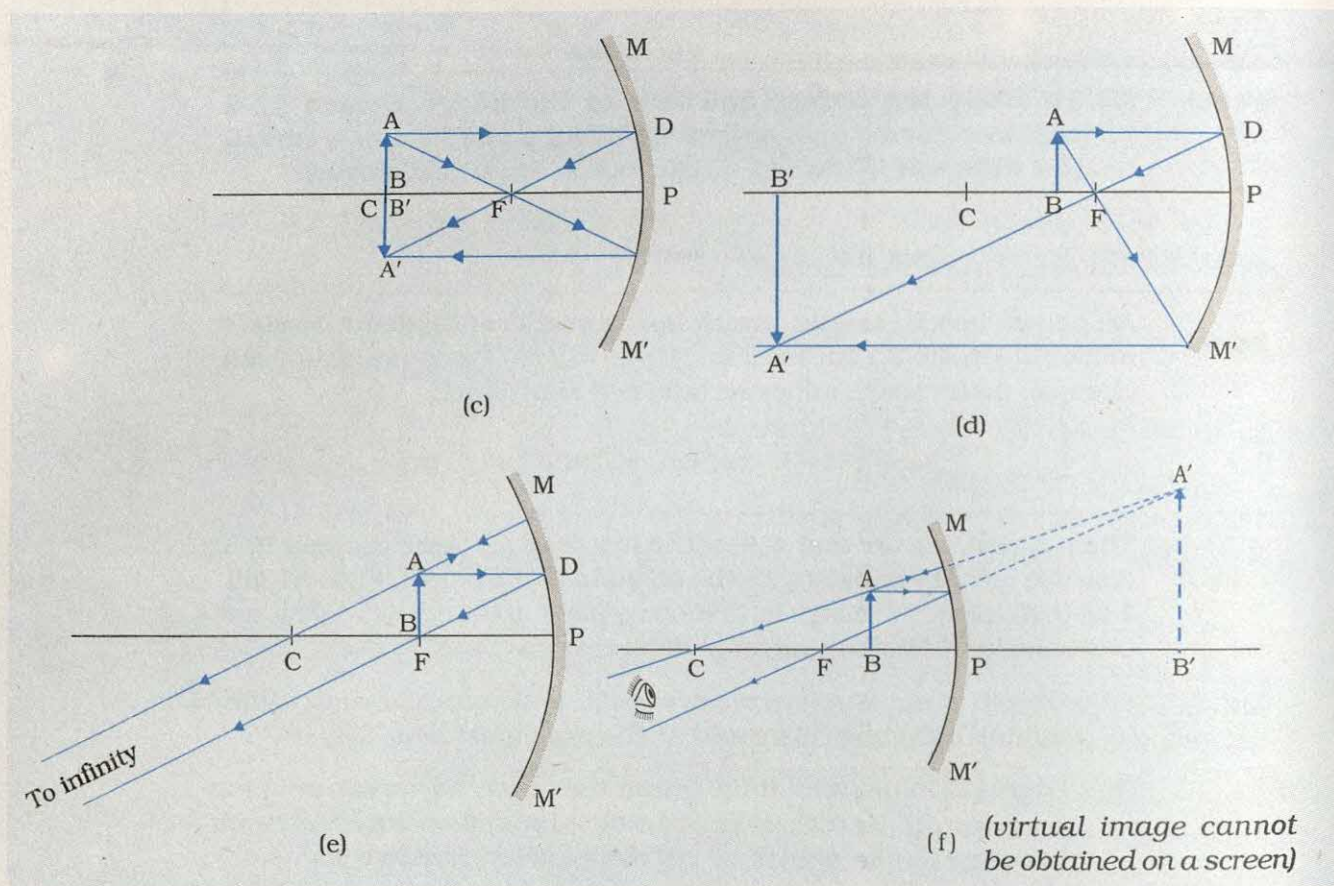


Fig. A 13 (ii).1 (a),(b),(c),(d),(e),(f) Formation of images by a concave mirror

- (d) Object is in between the centre of curvature and principal focus, i.e., $2f > u > f$. Real, inverted and enlarged image is formed in between C, the centre of curvature and infinity, i.e., $2f < v < \infty$.
- (e) Object is at the principal focus F, i.e., $u = f$. A highly enlarged, real and inverted image is formed at infinity, $v = \infty$.
- (f) Object is in between the principal focus F and pole of the mirror P, i.e., $f > u > 0$. An enlarged, virtual and erect image is formed behind the mirror.

A real image (always inverted) is the one through which the rays of light actually pass after reflection from concave mirror and which can be formed on a screen. A virtual image (always erect) is the one through which the rays do not actually pass, although they appear to come from it. Thus, the images of an object (e.g., a burning candle) formed for situations illustrated in Figs. A13 (ii).1 (a) to (d) can be focussed on a screen. The size of image may be determined by using a graph paper fixed on the screen.

PROCEDURE

1. Obtain an approximate value of the focal length of the concave mirror by focusing the image of a distant object. It can be found by obtaining a sharp image of the Sun or a tree on a plane wall, or on a sheet of paper and measuring the distance between the mirror and the image with a scale. This distance is an approximate value of the focal length, f of the concave mirror. Twice of this focal length is an approximate value of the radius of curvature of the mirror.
2. Place the optical bench on a rigid platform and using the spirit level make it horizontal with the help of levelling screws provided at the base of the bench.
3. Clamp the concave mirror on an upright and fix it near one end of the optical bench such that its principal axis is horizontal and parallel to the optical bench. In this position the mirror would lie in a plane perpendicular to the principal axis of the mirror.
4. Mount a lighted candle vertically on a small candlestand and fix it on an upright. Place this upright near the reflecting surface of the mirror. Adjust the upright so that the height of the bottom of the candle (or top of the candlestand) becomes equal to the height of the pole P of the mirror from the base of the optical bench. In this situation the bottom of the candle (or the top of the candlestand) would lie on the principal axis of the mirror.
5. Mount the screen on another upright and adjust the height of its top equal to the height of pole P from the base of the optical bench. Thus, the position of the screen lies below the principal axis of the mirror.

Note: In situations where $\infty > u > R$; $R > v > f$, the object is kept above the principal axis and screen is kept below the principal axis as shown in Fig. A 13 (ii).2(a).

6. Shift the candle upright to another end of the optical bench so that the distance of the candle from the mirror is much larger than the focal length of the concave mirror. Thus, the position of the candle in front of the mirror can be considered to be distant, i.e., $u \gg R$, and the image of the candle will be formed at a position much closer to the principal focus F of the mirror [Fig. A13 (ii).1 (a)] or $v \approx f$.
7. Read the positions of the mirror, screen and candle uprights on the optical bench metre scale and record the readings in the observation table.

8. Measure height of the lighted candle using the metre scale. Also measure the height of the image formed on screen as done in step 9 of activity 13 (i).
9. Bring the lighted candle close to the centre of curvature C (distance $PC = 2f$). Now the image will be formed in between the points C and F, close to $2f$. Adjust the position of the screen to get a sharp image [Fig. A 13 (ii). 1(b)].

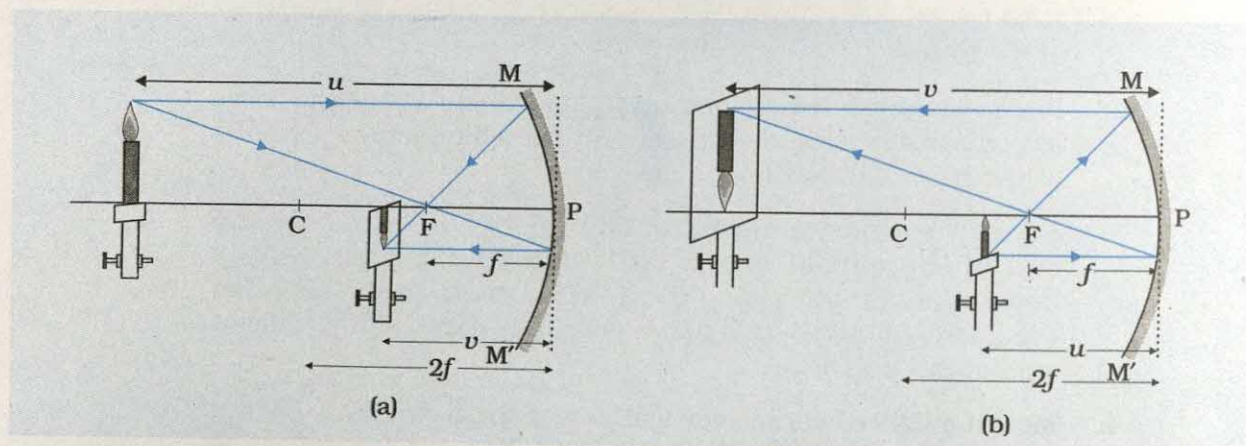


Fig. A 13 (ii). 2 Real images of a lighted candle formed by a concave mirror (a) $u > v$; and (b) $u < v$.

10. Place the candle at C. Shift the position of the screen near to the principal focus F on the optical bench. Use the rough estimated value of the focal length f of the mirror as determined in Step 1. Make final adjustments to get a sharp image of the lighted candle on the screen. Note the nature of the image.
11. Repeat steps 7 and 8 and record the observations and also note the nature of image formed.
12. Shift the lighted candle such that $R > u > f$. Now the image will be formed in between the point C and infinity, i.e., $\infty > v > R$ [Fig. A13(ii).1(d)]. Now since $u < v$, the candle (object) is placed below the principal axis while the screen is placed above the principal axis, i.e. the top of candle and bottom of the screen lie on principal axis as shown in [Fig. A13 (ii). 2 (b)].
13. Repeat above steps by placing the candle at F and then between F and P. Record your observations in Table A 13 (ii). 1.

Note: When candle is placed at the centre of curvature C (i.e., $u = R$), this method may not be useful for locating the position of image as it is difficult to mount both the screen and candle at the same place on the optical bench.

OBSERVATIONS

Approximate focal length of the concave mirror = ...cm

Table A 13 (ii).1: Nature, size and position of image with different positions of object

Sl. No.	Position of mirror (cm)	Position of candle (cm)	Size of flame (cm)	Position of image on the screen (cm)	Size of image (cm)	Nature of image (cm)	Relative size of image (cm)
1							
2							
...							
6							

RESULT

Observation on the nature, size and position of image shows that

1. The image moves away from the focus as the object is moved towards the focus.
2. The size of the image increases as it moves away from the mirror.
3. If the object is placed between infinity and F the image formed by a concave mirror is real and inverted.
4. If the object is placed between F and pole, the image is formed behind the mirror and it is virtual, erect and enlarged.

PRECAUTIONS

1. This experiment should be performed at a shaded place where no direct light reaches (preferably in a dark room) otherwise the images may not be distinctly visible.
2. While estimating the rough value of focal length f of the mirror by focusing the Sun, do not look at the Sun through the mirror as it may hurt your eyes.
3. The uprights supporting the optical elements should be rigid and mounted vertically.
4. The aperture of mirror should be small otherwise the image formed will not be distinct.
5. Eye should be placed at a distance more than 25 cm from the image being formed on the screen.

6. An error may arise in the observations if the top of optical bench is not horizontal.
7. The general instructions to be followed in all optical bench experiments must be taken care of.
8. The concave mirror should be front-coated. Otherwise multiple reflections coming from the reflecting surface of the mirror will confuse the accurate position of the image.

DISCUSSION

1. You cannot exactly observe the characteristics of the image formed when the object is between focus and pole of the mirror. You can only check by moving the screen in front of it that the image is not formed in front of the mirror. By drawing ray diagram it can be seen that the virtual image is formed behind the mirror.
2. The inferences corresponding to $u = \infty$ and $u = f$ also be elicited by the trends you observe and drawing ray diagrams, because, the object and image (respectively) are situated outside the range of optical bench.
3. The situation corresponding to $u = 2f$, may also be difficult to locate because you have to place the candle and the screen at the same position.

SELF ASSESSMENT

1. The focal length of a concave mirror is 20 cm, what is its radius of curvature?
2. When an object is placed at 30 cm in front of a concave mirror, image of the same size is formed. What is the focal length of the mirror?
3. Focal length of a concave mirror is 30 cm. What will be the characteristics of the image formed, when the object is placed at a distance of 40 cm in front of the mirror?
4. What is the effect on the size and intensity of the image formed when the lower half of the concave mirror is painted black?
5. Is it possible to get a virtual image on the screen? If so, how?
6. In a similar experiment using lenses, the images look a little coloured, unlike this experiment. What is the reason for this?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

Using a plane mirror and a single pin determine the focal length of a given convex lens.

ACTIVITY 14

Aim

To obtain a lens combination with specified focal length by using two lenses from a given set of lenses.

Apparatus and Material Required

A set of convex lenses of known powers, optical bench with uprights and screen, a source of light providing a parallel beam of light (a collimator).

Principle

A parallel beam of light parallel to principal axis after refraction through a lens either focus at a point or appears to diverge from a point on the principal axis called the focus point. The distance from the optical centre to the focal point is called the focal length.

Power of lens

The ability of a lens to converge or diverge the rays passing through it is called the power of the lens

$$\text{Power} = \frac{1}{\text{focal length (f)}}$$

Its SI unit is Dioptre. Power of a convex lens is taken as positive. Two or more lenses, placed in contact together to have a common principal axis, form a lens combination. If $f_1, f_2, \dots, f_n$ be the focal length of individual lens and F be the focal length of the combination, then

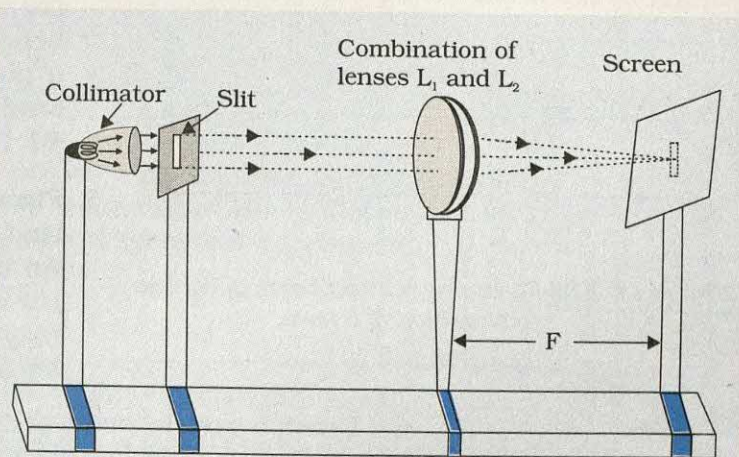


Fig. A 14.1 (a) Focal length of combination of lenses

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \dots + \frac{1}{f_n} \quad \text{or}$$

$P = P_1 + P_2 + \dots + P_n$, where P is the power of the lens combination and $P_1, P_2, \dots, P_n$ are the powers of the individual lenses. Fig. A 14.1(a).

PROCEDURE

1. Calculate the power of the combination of two lenses corresponding to the required focal length.
2. Select a lens from the given set of lenses whose power is smaller than that of the combination of lenses to be prepared, (if only convex lenses are provided).
3. Calculate the power of unknown convex lens to be kept in contact with the lens of known focal length to obtain a combination of lenses of desired focal length. Select the lens whose power is close to the calculated power from the given set of lenses.

4. Set up the optical bench on a horizontal table. Adjust the collimator to direct parallel beam of light along the optical bench. In case collimator is not available, a plane mirror may be used to direct sunlight along the optical bench [Fig. A 14.1 (b)] and illuminate a slit with it.

5. Place the two lenses on the uprights such that they are in contact with each other. An upright that can hold two lenses in contact may also be used or the same may be improvised by fixing the lenses on grooves carved on a thermocole sheet.

6. Direct a parallel beam of light on the combination of lenses and obtain a sharply focussed image of the source of light on a screen placed on the other side of the lenses. This can be done by adjusting the distance between the combination of lenses and screen.
7. Measure the distance of the screen from both the lenses and record it in a table.
8. Repeat the activity atleast three times by changing the position of the lens combination on the optical bench. Record your observations in each case.

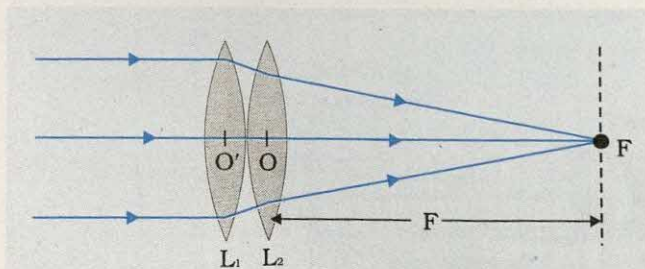


Fig. A 14.1 (b) Focussing parallel beam of light on combination of lenses

OBSERVATIONS

Focal length of lens $L_1 = f_1$

Focal length of lens $L_2 = f_2$

Calculated focal length of lens combination $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$

Least count of the scale of the optical bench = ...mm.

Table A 14.1: Focal length of combination of lenses

Sl. No.	Distance of first lens from the screen d_1 (cm)	Distance of second lens from the screen d_2 (cm)	Mean distance of screen from lens combination $\frac{d_1 + d_2}{2} = F$ (cm)
1			
2			
3			

CALCULATIONS

The mean distance of the screen from the lens combination is a measure of its focal length. Take average of all readings as the focal length of the combination determined by the experiment.

RESULT

Measured value of focal length of lens combination = ...cm

Difference between measured value of focal length and the calculated focal length = ...cm

The difference between the two could be due to experimental error.

SOURCES OF ERROR

1. Thickness of the lenses may cause an error.
2. The peripheral region of the lenses are not in contact.
3. Spherical aberration of the lenses may cause an error in locating the position of the sharp image, i.e., the exact focal length.

DISCUSSION

1. A source rendering parallel beam of light may be obtained by placing a torch bulb at the focus of a convex lens of known focal length.
2. You can make lens combinations using a pair of lenses separated by a distance d and adjusting the separation between them. You may obtain the combination of desired focal length using the formula,

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$

What is the range of focal lengths you may obtain this way?

SELF ASSESSMENT

1. A convex lens of focal length 20 cm is put in contact with a concave lens of focal length 10 cm. What will be the effective focal length of the combination?
2. If a convex lens is dipped completely in water, what will be the effect on its focal length?
3. If two lenses of focal lengths f_1 and f_2 are placed distance d apart, is the formula $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$ still valid? If not, give the modified formula. Will the focal length of the combination be (i) $< F$ (ii) $> F$?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. A person having refractive error is able to see distant objects clearly but is not able to read a book. We find that she can read the book clearly on using a combination of lenses of focal lengths 2, 2/3m and -1m, available in the laboratory. What should be the power of the lens to be prescribed for such a person?
2. Select a pair of lenses whose combination (i) will act as a converging lens (ii) will not act as a converging lens.

AIM

To determine the wavelength of a laser beam by diffraction.

APPARATUS AND MATERIAL REQUIRED

A He-Ne or semiconductor laser, a shining steel scale with mm graduations, one metre scale, clamp stand, a graph paper sheet mounted on a card board.

TERMS AND DEFINITIONS

Laser: Light Amplification by Stimulated Emission of Radiation (abbreviated as LASER).

Diffraction: The phenomenon of bending of light from narrow holes or slits.

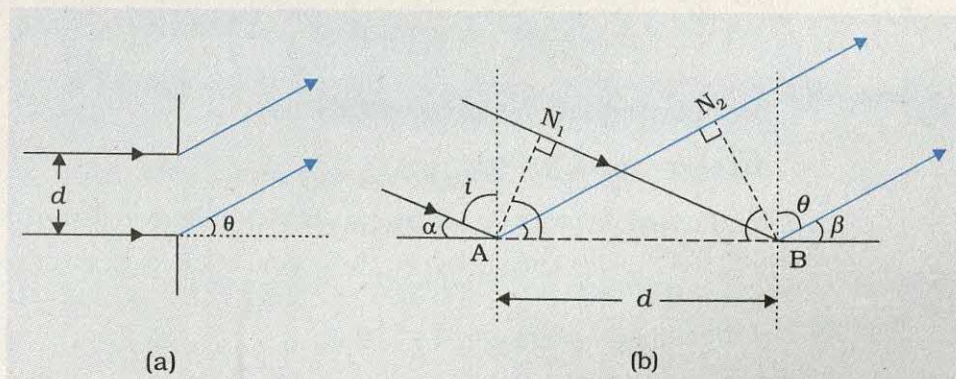


Fig. P 1.1 Single slit diffraction (a) normal incidence (b) oblique incidence

PRINCIPLE

If a parallel beam of light of wavelength λ falls normally on a single slit of width d (as shown in Fig. P 1.1(a)) the central maximum of the diffraction pattern occurs at $\theta = 0$ and subsequent maxima appear at

$$\sin \theta = \left(n + \frac{1}{2} \right) \frac{\lambda}{d}, \quad n \neq 0$$

Consider now, many such “slits” equally spaced as in a shiny steel scale. Also the angle of incidence of the light beam may be close to 90° .

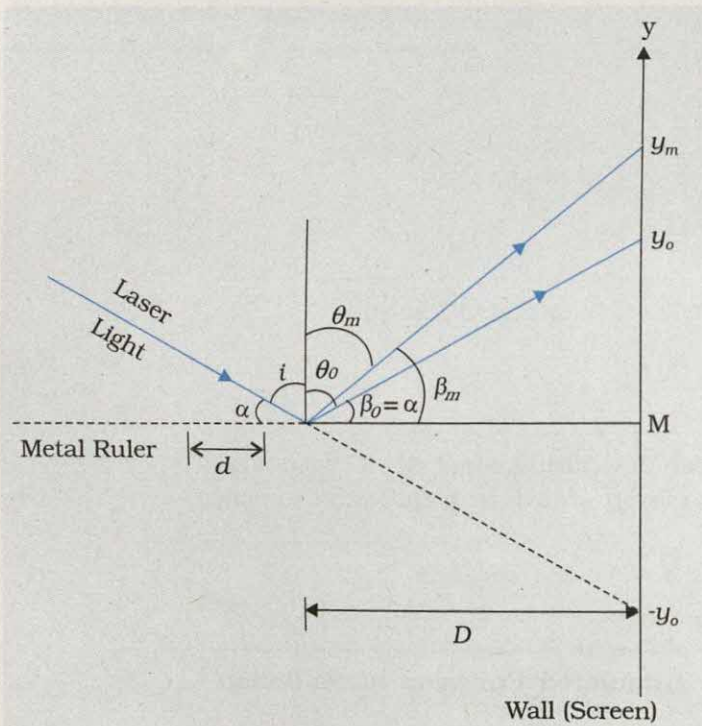


Fig. P 1.2 Schematic diagram of the experimental arrangement

Referring to Fig. P1.1(b), the path difference between the incident and diffracted beam is

$$(N_1B - AN_2) = d (\sin i - \sin \theta)$$

i is Angle between the incident ray and the perpendicular.

If the engravings on a metal scale are used for diffraction of light of wavelength λ incident at an angle of incidence $i \leq 90^\circ$, for the m^{th} order maximum, diffracted at an angle θ_m as shown in Fig. P1.2, we have

$$d(\sin i - \sin \theta_m) = m\lambda$$

where the spacing d between successive engravings is constant.

If $d = 1\text{mm}$

α = Angle between incident ray and the steel scale

$$\alpha = \left(\frac{\pi}{2} - i \right) \text{ and } \beta_m = \left(\frac{\pi}{2} - \theta_m \right)$$

The above equation can be written as

$$d(\cos \alpha - \cos \beta_m) = m\lambda$$

For the zeroth order ($m=0$), the beam is peculiarly reflected and $\alpha = \beta_0$.

Let D be the distance between the region of incidence at the scale and the screen. The diffraction spots lie along the y -axis, and the position of the m^{th} spot is represented by y_m .

From Fig. P1.2

$$\cos \beta_m = \frac{D}{\sqrt{D^2 + y_m^2}} = \frac{D}{D \sqrt{1 + \left(\frac{y_m}{D} \right)^2}}$$

$$\cos \beta_m = \left[1 + \left(\frac{y_m}{D} \right)^2 \right]^{-1/2}$$

(P 1.1)

$$= 1 - \frac{1}{2} \frac{y_m^2}{D^2} + \dots$$

Using binomial expansion ($\because y_m \ll D$ for all m)

$$\text{and } \cos \alpha = \cos \beta_0 = 1 - \frac{1}{2} \frac{y_0^2}{D^2} + \dots$$

$$\therefore \cos \alpha - \cos \beta_m \approx (y_m^2 - y_0^2) / 2D^2 = \frac{m\lambda}{d} \text{ from Eq. (P1.1)}$$

Thus, wavelength of the light is given by

$$\lambda = d(y_m^2 - y_0^2) / 2mD^2.$$

PROCEDURE

1. Clamp the metal scale in the horizontal position on a stand.
2. Clamp the laser source on another stand, near the edge of the scale.
3. Place both stands on the table keeping the distance between them about 20 cm, also both should be at the same height.
4. Fix a graph sheet on a wall facing the laser source and at a distance of 3-4 m from the scale.
5. Turn on the laser source and incline the same such that the laser beam strikes the grooves on the scale at a grazing angle such that diffraction spots are observed on the graph.
(You may need to adjust the position and orientation of the scale and the source to observe the spots on the graph sheet).
6. Now keep the position and orientation of laser and the scale fixed.
7. Mark position of various diffraction spots on the graph paper.
8. Remove metal scale and observe the spot directly coming from the laser source on the graph paper. Mark this position as $(-y_0)$.
9. Find the mid point of direct beam position $(-y_0)$ and first spot (y_0) on the graph and mark it as M.
10. Now measure the distance of the second spot (y_1) from M.
11. Repeat steps 7 to 10 for obtaining readings for 2nd and 3rd order of diffraction pattern.

OBSERVATIONS

For First Order

$$d = 1\text{mm}$$

$$D = \dots \text{m}$$

Distance of 1st spot from $M(y_0) = \dots y_0$

Distance of 2nd spot from $M(y_1) = \dots y_1$

Observations for 2nd and 3rd order - Same as for 1st order.

CALCULATIONS

Calculate the value of $(y_1^2 - y_0^2)$ for each set and then find the average value of $(y_1^2 - y_0^2)$

Use the average value in the formula

$$\lambda = \frac{d(y_1^2 - y_0^2)}{2D^2}$$

Find the value of λ .

RESULT

Wavelength of laser beam = ... m

DISCUSSION

1. While considering from obstacles of the order of 1mm, why is it necessary to consider grazing incidence of the visible light?

Can diffraction be observed when $i = 45^\circ$?

2. Lattice constant of a sodium crystal is $1\text{\AA}$. Can you obtain diffraction of a laser light from a sodium crystal?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

Using the same principle as in this project, measure the width of a pencil by placing a bunch of them adjacent to each other as shown in Fig. P 1.3 below.

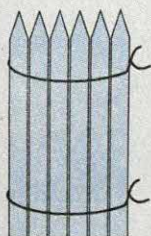


Fig. P 1.3 A bunch of pencils placed touching each other

A_{IM}

To study various factors on which the internal resistance of a cell depends.

A_{PPARATUS AND MATERIAL REQUIRED}

Potentiometer, battery, three one way keys, a rheostat of low resistance, a galvanometer, a high resistance box, a fractional resistance box, an ammeter, a voltmeter, a voltaic cell, electrolytes of different concentrations, a jockey, connecting wires and sand paper.

T_{ERMS AND DEFINITIONS}

1. *Internal resistance*: The resistance offered by the electrolyte of a cell to the flow of current through it.
2. *EMF (E)*: Potential difference of a cell in an open circuit i.e., when no current is drawn from it.

P_{RINCIPLE}

Principle of a potentiometer: Potential difference across the length of a conductor of uniform area of cross-section carrying steady current is directly proportional to its length.

The internal resistance of a cell depends on

- (i) distance between the plates (electrodes)
- (ii) common area of the electrodes immersed in the electrolyte and
- (iii) concentration of the electrolyte.

P_{ROCEDURE}

1. Prepare a cell filled with an electrolyte of given concentration (Fig. P 2.2).

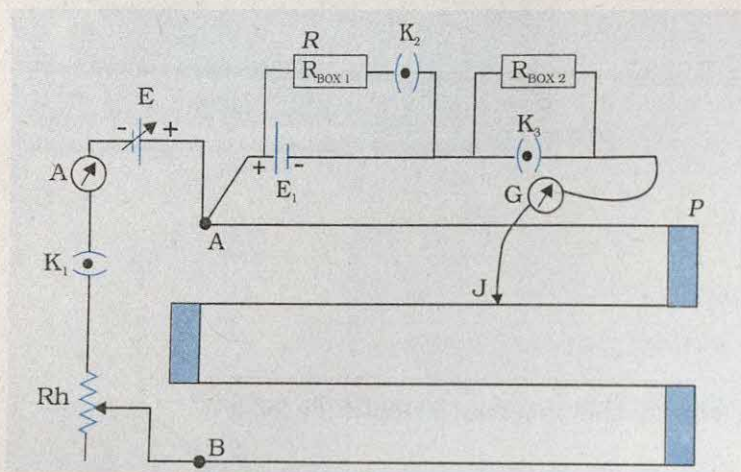
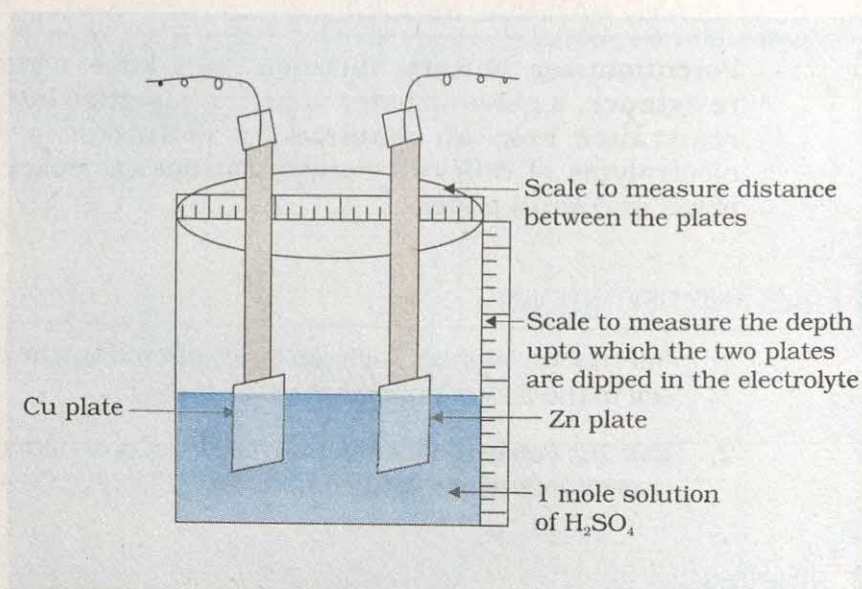


Fig. P 2.1 Circuit to measure internal resistance of a primary cell using potentiometer

Fig. P 2.2 Voltaic cell with an electrolyte of given concentration



2. Arrange the circuit, as done for the determination of internal resistance of a cell (Fig. P 2.1) (Refer Experiment E 5).
3. Determine the internal resistance of the given cell as described in Experiment E 5.

OBSERVATIONS AND CALCULATIONS

1. Effect of separation between the plates

Determine the internal resistance of the cell for different separations between the plates with the same electrolyte. Keep the common area of the plates immersed in electrolyte same throughout your observation. Record the observations in Table P 2.1.

Table P 2.1: Dependence of internal resistance on separation between the plates

Sl. No.	Separation between plates (cm)	R (Ω)	Balancing length (cm)		Internal Resistance $r = R \times \left(\frac{l_0 - l}{l} \right)$ (Ω)
			Open circuit (when keys K_2 and K_3 are open)	Closed circuit (when keys K_2 and K_3 are closed)	
			length l_0 (cm)	length l (cm)	
1					
2					
3					

II. Effect of common area of plates immersed in electrolyte

Determine the internal resistance of the cell by changing the depth upto which the two plates are immersed in the electrolyte or by changing the level of electrolyte in the cell. Record the observations in Table P 2.2.

Breadth of plate : ... cm.

Table P 2.2: Dependence of internal resistance on common area of plates immersed in electrolyte

Sl. No.	Length of the plate immersed in the electrolyte (cm)	R (Ω)	Balancing length (cm)		Internal Resistance $r = R \times \left(\frac{l_0 - l}{l} \right)$ (Ω)
			Open circuit (when keys K_2 and K_3 are open)	Closed circuit (when keys K_2 and K_3 are closed)	
			length l_0 (cm)	length l (cm)	
1					
2					
3					

III. Effect of concentration of the electrolyte

Maintain a constant distance between the two plates and keep their area immersed in the electrolyte same. Determine the internal resistance of the cell by filling it with electrolyte of given concentration. Repeat this measurement with electrolytes of varying concentrations, but filling the cell upto the same level in every case. Record the observations in Table P 2.3.

Table P 2.3: Dependence of internal resistance on the concentration of the electrolyte

Sl. No.	Concentration of the electrolyte (in moles)	R (Ω)	Balancing length (cm)		Internal resistance $r = R \times \left(\frac{l_0 - l}{l} \right) (\Omega)$
			Open circuit (when keys K_2 and K_3 are open)	Closed circuit (when keys K_2 and K_3 are closed)	
			length l_0 (cm)	length l (cm)	
1					
2					
3					

RESULT

1. Internal resistance of a cell increases with increase in distance between the electrodes.
2. Internal resistance increases with decrease in common area of electrodes immersed in the electrolyte.
3. Internal resistance increases with decrease in concentration of the electrolyte.

PRECAUTIONS

1. Ensure that the emf of battery E is greater than emf of cell E_1 .
2. Positive terminals of E and E_1 both should be connected at terminal A of the potentiometer.
3. The current should not be passed for a long time so as to avoid any heating of the wires resulting in the change of resistance.

4. The length of the wire should always be measured from the end A of the wire, where all the positive terminals are connected.
5. Jockey should not be pressed too hard on the wire, otherwise the diameter of the wire may not remain uniform. Also do not press the jockey on the wire while sliding it.

SOURCES OF ERROR

1. Potentiometer wire may not be of uniform area of cross-section throughout its entire length.
2. The emf of the auxiliary battery producing the fall of potential along the potentiometer may not be constant throughout the course of experiment.
3. End resistance of potentiometer wire are not taken into account.
4. Heating of the potentiometer wire due to current, may introduce some error.

DISCUSSION

1. Internal resistance of a cell also depends upon temperature. Temperature of the electrolyte should therefore be kept constant throughout.
2. In order to protect the galvanometer from damage due to excessive current, a high resistance should be connected in series with it while obtaining approximate position of the balance point. This does not affect the position of the balance point in any way. However, this resistance should be removed while trying for the exact position of the balance point. The same purpose can be achieved by using a shunt across the galvanometer.
3. Internal resistance also depends upon the current drawn, so the current drawn should not change appreciably.
4. The resistance of a conductor increases with its length, hence the internal resistance of a cell increases with separation between the plates.
5. The resistance of a conductor varies inversely with its area of cross-section. Hence, the internal resistance of a cell increases with decreasing common area between the plates.
6. The conductivity of an electrolyte depends on the degree of dissociation of the electrolyte.

SELF ASSESSMENT

1. What inference would you draw on getting deflection in the galvanometer in one direction only?
2. Can R , the external resistance across the cell be varied over a large range?
3. How can the sensitivity of the potentiometer be increased?
4. You are given two cells A and B. Cell A is freshly prepared and cell B has been in use for some time. Which of the two has less internal resistance?

A_{IM}

To construct a time switch and study the dependence of its time constant on various factors.

A_{PPARATUS AND MATERIAL REQUIRED}

A battery (6 V), a bulb (6 V, 0.06 A), a relay (magnetic - 185 Ω), a transistor (n-p-n BC 108), two switches S_1 and S_2 , resistors of $\frac{1}{2}$ W each (5 k Ω , 10 k Ω , 15 k Ω), capacitors (electrolytic type, 500 μ F, 1000 μ F, 2000 μ F), connecting wires and a stop watch.

P_{RINCIPLE}

When a capacitor of capacitance C is allowed to get charged through a resistance R , then the charge acquired by the capacitor at any instant of time is given by $q(t) = q_0 [1 - e^{-t/\tau}]$ where $\tau = RC$ is the time constant.

The time constant of a circuit is defined as the time taken by the capacitor to acquire 63.7 per cent of the maximum charge while charging.

P_{ROCEDURE}

1. Arrange the components and make the circuit as shown in Fig. P 3.1.
2. Close the switch S_1 and start the stop watch. The lamp L is switched ON and the capacitor C starts getting charged through the resistance R .
3. After sometime, the voltage across the capacitor would exceed a threshold value so that a base current begins to flow through the transistor T and hence a collector current also flows. This breaks the relay contacts and the bulb goes OFF. Now stop the stopwatch as soon as the lamp goes OFF. Note the time interval and compare it with the product of R and C .
4. Use three values of C e.g. 500 μ F, 1000 μ F, 2000 μ F keeping the value of R (say 5 k Ω) fixed and measure time interval in every

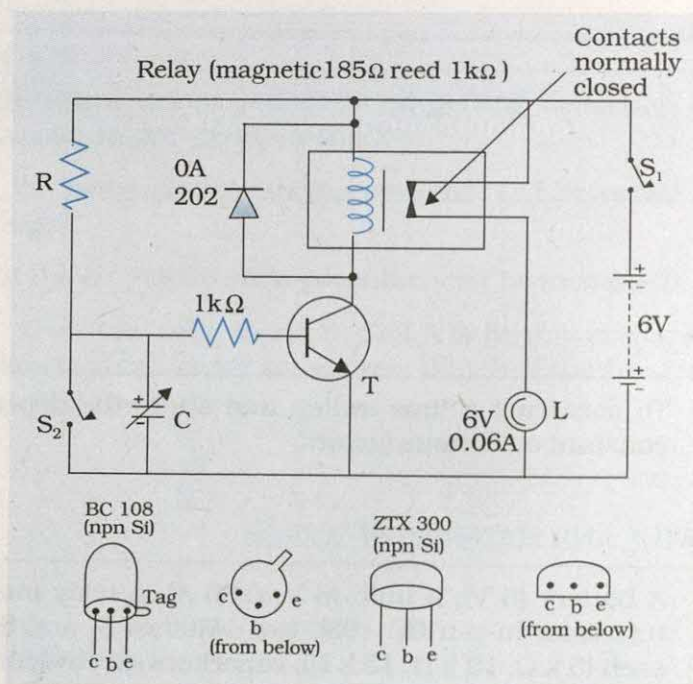


Fig. P 3.1 Circuit of a time switch

case. Repeat the procedure by keeping $R = 10\text{ k}\Omega$ and $15\text{ k}\Omega$. Record the observations in Table P 3.1.

- Use three values of R (e.g. $5\text{ k}\Omega$, $10\text{ k}\Omega$, and $15\text{ k}\Omega$), keeping the value of C fixed (say $c = 500\mu\text{f}$) and again measure the time interval between ON and OFF. Repeat the procedure by capacitors of $C = 1000\mu\text{f}$ and $2000\mu\text{f}$. Record observations in Table P 3.2.

OBSERVATIONS AND CALCULATIONS

Least count of stop watch = ... s

Table P 3.1: Time interval when R is constant

S. I. No.	$R_1 = 5\text{ k}\Omega$		Product RC (s)	$R_2 = 10\text{ k}\Omega$		Product RC (s)	$R_3 = 15\text{ k}\Omega$		Product RC (s)
	Value of $C (\mu\text{F})$	Time interval (s)		Value of $C (\mu\text{F})$	Time interval (s)		Value of $C (\mu\text{F})$	Time interval (s)	
1									
2									
3									

Table P 3.2: Time interval when C is constant

Sl. No.	$C_1 = 500 \mu\text{F}$		Product RC (s)	$C_2 = 1000 \mu\text{F}$		Product RC (s)	$C_3 = 2000 \mu\text{F}$		Product RC (s)
	Value of R (k Ω)	Time interval (s)		Value of R (k Ω)	Time interval (s)		Value of R (k Ω)	Time interval (s)	
1									
2									
3									

RESULT

Time operated switch is ready and the product RC is the time constant.

PRECAUTION

Check carefully the circuit and various components connected to it. Take special care to avoid any dry soldering.

SELF ASSESSMENT

If instead of n-p-n transistor, a p-n-p transistor is used in the given circuit, how will you change the circuit?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

A capacitor can be connected in parallel with the load in a full wave rectifier to smoothen the pulsating dc obtained from it. Relate the charging and discharging of the capacitor to this smoothening action of the capacitor filter. Also discuss, will the smoothening improve if a capacitor of larger capacitance is used.

PROJECT 4

AIM

To study infrared radiations emitted by different sources using phototransistor.

APPARATUS AND MATERIAL REQUIRED

A phototransistor, milliammeter (0 – 30mA), two 6 V batteries, infrared sources such as an IR LED, incandescent lamps (40 W, 60 W, 100 W), variable resistance, resistors (1k Ω 5 k Ω), Keys, connecting wires.

DESCRIPTION OF APPARATUS/DEVICES

Phototransistor: A photodetection device in which an electric current is obtained at the collector when light falls on its base region.

A tungsten incandescent lamp (domestic light bulb) is also a source of both visible and *infrared radiations*.

TERM AND DEFINITION

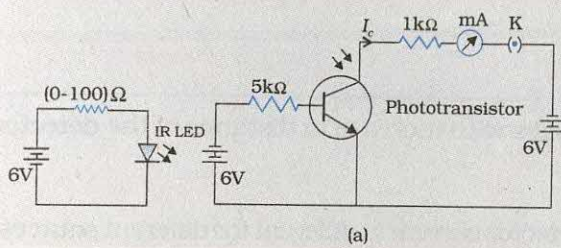
Electromagnetic radiations in the frequency range of 10^{11} Hz to 10^{14} Hz are called *infrared radiations* since their wavelength is greater than that of the visible red.

PRINCIPLE

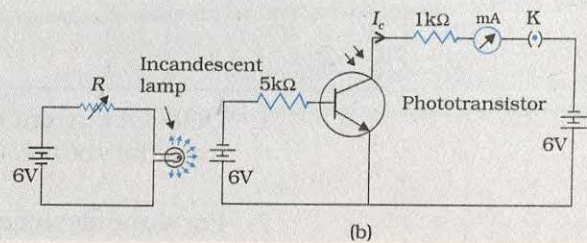
The magnitude of the current in the collector circuit depends on the intensity of the incident radiation falling on the base region.

PROCEDURE

As the photodetector is a sensitive device, house the source and the detector in a closed box so that stray radiations (visible/IR) are totally cut off. Moreover, you should be able to change the separation between the source and the detector and also measure the separations as well, without changing their relative orientation. The entire assembly of the devices is as shown in Fig. P 4.1.



(a)



(b)

Fig. P 4.1 (a) Circuit to measure IR radiation from IR LED using phototransistor

Fig. P 4.1 (b) Circuit to measure IR radiation from incandescent lamp using phototransistor

First maximise the current in the IR detector by placing the IR LED/incandescent lamp close to the detector. Measure this distance. Note down the ammeter reading. Now increase this distance in steps and note down the corresponding ammeter reading and record your observations in tabular form.

Repeat your observations for different sources (incandescent lamps).

OBSERVATIONS

Range of the milliammeter = ...mA

Least count of the milliammeter = ...mA

Initial reading of the milliammeter = ...mA

Table P 4.1: Detector current for different sources

Sl. No.	Source	Power input	Position of detector w.r.t. the source x (cm)	Detector current I (mA)
1	IR LED	small	(i)	
			(ii)	
			(iii)	
			(iv)	
2	Bulb	40 W	(i)	
			(ii)	
			(iii)	
			(iv)	
3	Bulb	60 W	(i)	
			(ii)	
			(iii)	
			(iv)	
4	Bulb	100 W	(i)	
			(ii)	
			(iii)	
			(iv)	

RESULT

1. Detector current changes with increase in distance of the detector from the source.
2. For same distances, detector current is different for different sources.

PRECAUTIONS

1. Connections should be neat and tight.
2. Source and detector should be enclosed in a closed box so that stray radiations are cut off.

SOURCES OF ERROR

1. Stray radiations may not be cut off completely.
2. Least count of milliammeter may cause an error.

DISCUSSION

1. In the circuit shown in Fig. P 4.1 there is a provision to change IR LED current. Do you think it will affect the intensity of emitted radiation or the frequency of radiation or both? Try the same setup using red, yellow and green LEDs instead of the IR LED.
2. The detector material is sensitive to IR. What do you think would be the value of its work function?
3. If you repeat this experiment with the same detector, but with a microwave source, do you think there will be any detector current?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. One can use the above set up to study the effect of frequency of light sources on the detector current, by using different coloured filters. We can use red, orange, yellow, green, blue filters and show how detector gives no current for red and orange light, but gives current for green and blue filters.
2. Draw the detector position (x) versus detector current (I) graph for each set of observations.

AIM

To design an automatic traffic signal system using suitable combination of logic gates.

APPARATUS AND MATERIAL REQUIRED

LEDs (of red, yellow, green colours) four each, one IC 555 timer, one IC 7490, two NOT gates (or a single IC 7400), four NAND gates (or single IC 7400), capacitors of $0.1\ \mu\text{F}$, $10\ \mu\text{F}$ (16 V), resistors of $5.6\ \text{k}\Omega$, $150\ \text{k}\Omega$ (1 W) each, four resistors of $220\ \text{k}\Omega$ (1 W) each, two resistors of $47\ \text{k}\Omega$ (1 W) each, battery, switch.

PRINCIPLE

Integrated circuit (IC) is an extremely small sized electronic circuit which incorporates a whole system of electronic components and devices. Depending on the number of components fabricated on a chip, the integrated circuits are classified into various classes; 555 timer, IC 7400 etc. are examples of MSI (Medium Scale Integrated) circuits. Any logic gate operation can be achieved by using suitable IC's.

The basic arrangement of traffic light system which is used at a common road-crossing is shown in Fig. P 5.1.

Each traffic light system uses red, yellow and green lights. These days LEDs are used for this purpose (represented here by $R_1, Y_1, G_1; R_2, Y_2, G_2; R_3, Y_3, G_3$ and R_4, Y_4, G_4). In traffic light system, usually the lights of the same colour on the opposite sides of the cross roads are either ON or OFF simultaneously, so the LED pairs R_1 and

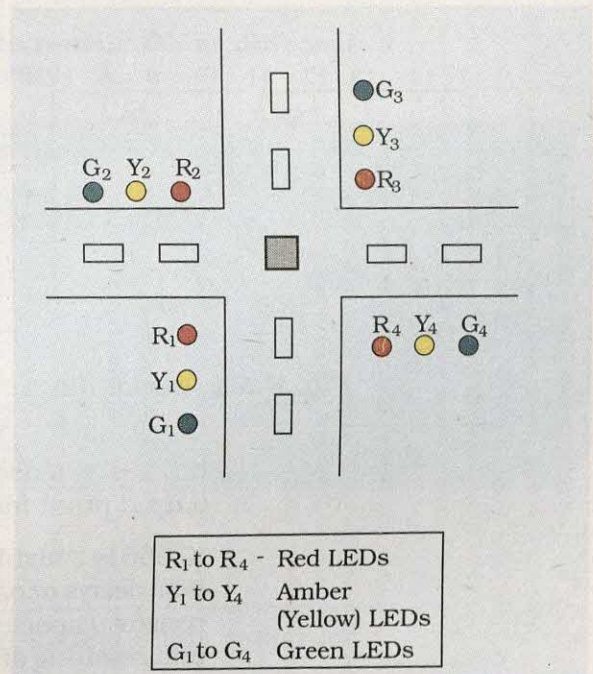


Fig. P 5.1 Schematic diagram of basic road traffic light system

R_3 , R_2 and R_4 , Y_1 and Y_3 , Y_2 and Y_4 , G_1 and G_3 and G_2 and G_4 are connected in series. This arrangement is shown in Fig. P 5.2.

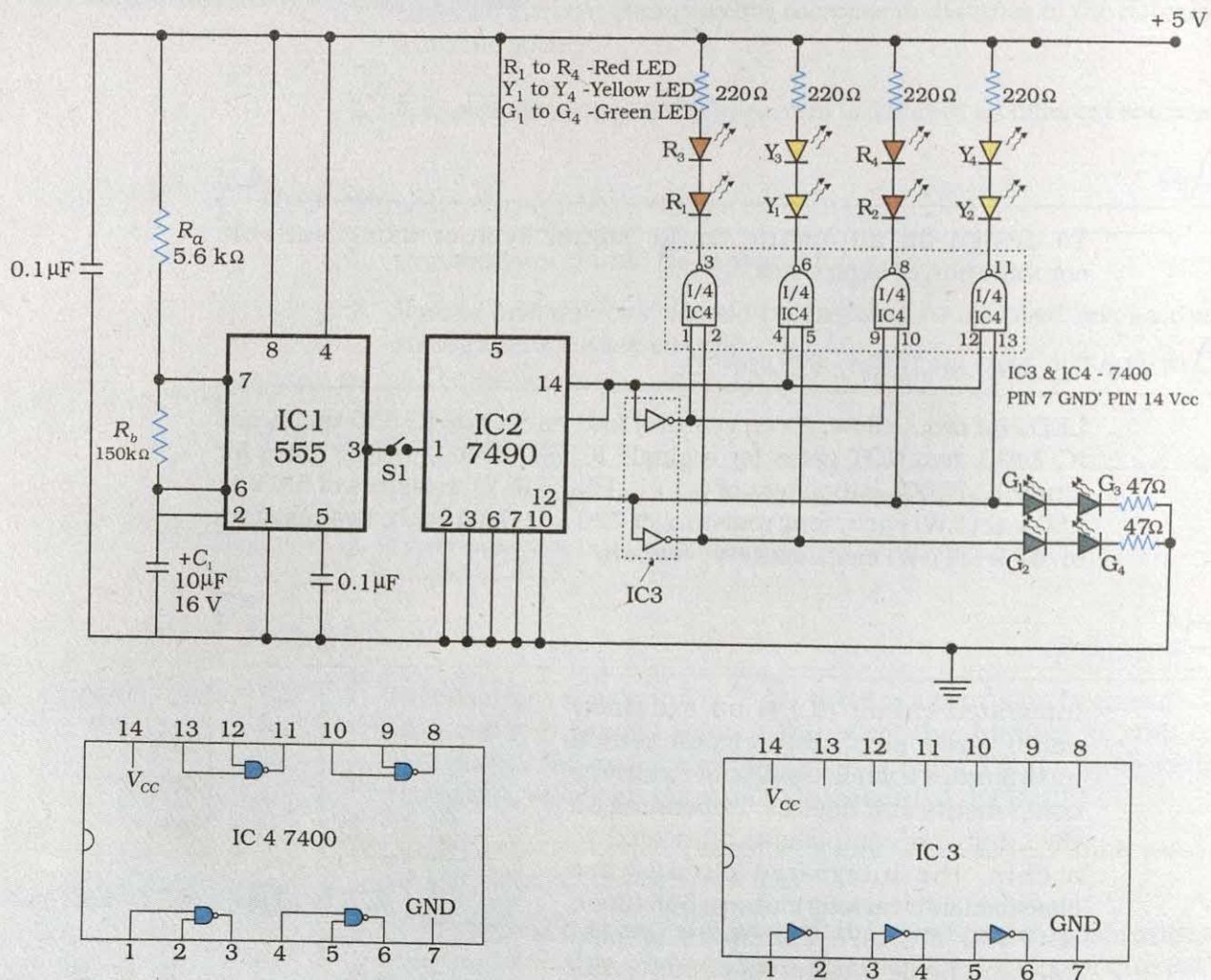


Fig. P 5.2 Circuit diagram of basic circuit for automatic traffic light

IC 7490 is a decade counter. As the name suggests, it produces one output pulse for every 10 input pulses.

IC 555 is a highly stable timing circuit capable of producing accurate time delays or oscillations. The time period is controlled by an external resistor-capacitor combination. There is also a provision for triggering and resetting of the timer.

In this traffic light system if the red light will remain ON for 8 seconds (or 8 units of time), the yellow light for 2 seconds and green light for 10 seconds then the ratio of timings of red, yellow and green lights is

4:1:5. IC 555 acts as a timer IC which works on the principle of charging and discharging of a capacitor connected in series with the resistor and that gives high or low output after a regular interval of time. In the present situation, it is used to give a square wave output whose time period can be varied by using suitable values of resistances R_a and R_b and capacitance C_1 . The time period of such timer is given by

$$T = 0.693 (R_a + R_b) C_1 \sim 0.693 R_a C_1 \text{ since } R_a \gg R_b$$

IC 7490 performs the function of a decade counter.

PROCEDURE

1. Connect the components as per the circuit arrangement shown in Fig. P 5.1.
2. Take a plywood board and paint it in black colour (road colour).
3. Mount the LEDs $R_1, Y_1, G_1; R_2, Y_2, G_2; R_3, Y_3, G_3; R_4, Y_4, G_4$ on four different strips and fix the four strips on the suitable four sides of the road crossing.
4. Check the circuit connections twice and close the switch S_1 for functioning of the traffic light system.

OBSERVATIONS

Table P 5.1 : Requirements of lights to remain ON at different counts of time (1:ON, 0:OFF)

Units of time (s)	R_1, R_3	Y_1, Y_3	G_1, G_3	R_2, R_4	Y_2, Y_4	G_2, G_4
0 to 3	1	0	0	0	0	1
4	0	1	0	0	0	1
5 to 8	0	0	1	1	0	0
9	0	0	1	0	1	0

RESULT

By closing the switch S_1 the traffic light system starts action for demonstration.

P RECAUTIONS

1. Take sufficient care in soldering the components used in the circuit arrangement in order to avoid dry solder joints.
2. Use IC base so as not to damage the IC by directly soldering it.

S SELF ASSESSMENT

1. Design a circuit for traffic signal system using LEDs and a delay circuit only.
2. Design the basic gates (OR, AND, NOT) using NAND gates.

PROJECT 6

AIM

To study the luminosities of various electric lamps of different powers and make.

APPARATUS AND MATERIAL REQUIRED

Optical bench with suitable stands, Bunsen's grease spot photometer, bulbs of different powers and make, one standard lamp.

DESCRIPTION OF APPARATUS

Description of Bunsen's grease spot photometer:

A matt paper is fixed in a circular frame and a grease spot is formed at its centre which leaves the paper translucent at that place. The screen so formed is fixed on a vertical stand which rests at the mid point of the optical bench. On one side of the photometer is mounted a standard lamp and on the other side an electric bulb in such a way that the filaments of the two bulbs and grease spot are in the same line as the bed of the optical bench.

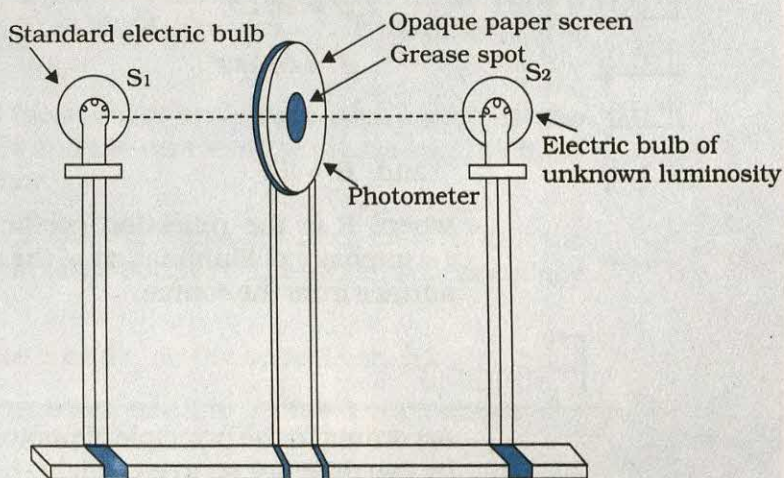


Fig. P 6.1 A grease spot photometer

TERMS AND DEFINITIONS

1. **Photometry:** The branch of Physics, which deals with the study of luminosities of different sources of light in the visible range and the intensities of illuminations of surfaces.

2. *Illuminating power or luminosity (L) of a source*: It is defined as the amount of energy in the visible range falling per second per unit surface area held at a unit distance from the source when surface is held normal to the light rays. It is denoted by L . Its unit is candela.
3. *Luminous flux*: It is defined as the total energy in the visible range emitted per second by a source in all directions. Its SI unit is lumen.
4. *Intensity of illumination (I) at a point on a surface*: It is defined as the amount of energy in the visible range falling per second per unit area of the surface around that point. Its SI unit is Lux.
5. *Brightness of a surface (B)*: Brightness of a surface in a given direction is defined as luminosity coming from the unit area of the surface.

RELATIONSHIP

The luminous flux ϕ , luminosity L , and intensity of illumination I are related by the following equation,

(P 6.1)

$$\phi = 4\pi L$$

(P 6.2)

$$I = \phi / 4\pi r^2$$

(P 6.3)

$$I = L / r^2$$

(P 6.4)

$$\text{and } B = IR$$

where R is the reflection coefficient ($0 < R < 1$) of the surface, I = intensity of illumination of the source and r is the distance of the surface from the source.

PRINCIPLE

According to the principle of photometry, if two surfaces, illuminated by two different sources of light, have the same brightness, then the illuminating powers of the two sources are directly proportional to the square of their respective distances from the surfaces, of the same R , thus

(P 6.5)

$$\frac{L_1}{L_2} = \frac{r_1^2}{r_2^2}$$

THEORY

In a grease spot photometer, two sources of light S_1 and S_2 are placed on opposite sides of the screen at such distances that the grease spot and remaining surface of the screen appear equally bright. In that case, the intensity of the two sides of the screen will be the same.

Let I_1 and I_2 be the intensities of illuminations of the screen due to the sources S_1 and S_2 of illuminating powers L_1 and L_2 placed at distances r_1 and r_2 from the screen.

Then

$$I_1 = I_2 \quad \text{(P 6.6)}$$

or

$$\frac{L_1}{r_1^2} = \frac{L_2}{r_2^2} \quad \text{(P 6.7)}$$

or

$$\frac{L_1}{L_2} = \frac{r_1^2}{r_2^2} \quad \text{(P 6.8)}$$

If the source S_1 is taken as a standard source of known illuminating power, then using the relation (P 6.8), the illuminating powers of bulbs of different powers and makes can be found out.

PROCEDURE

1. Adjust the stand of grease spot screen at a suitable height on the optical bench.
2. Fix the electric lamp of known wattage on one side of the screen and the other electric lamp of different wattage on the other side of the screen.
3. Adjust the heights of the stand or uprights in such a way that the filaments of two bulbs and the centre of the grease spot, all lie in the same horizontal line.
4. Adjust the distances of both the lamps in such a manner that the grease spot and the rest of the surface of the screen appear equally bright.
5. Measure the distances r_1 and r_2 on the optical bench.
6. Find the index correction and use it to get the correct values of r_1 and r_2 .

OBSERVATIONS

1. Power and make of standard lamp = ...

(a) Bulbs of same wattage but different makes

Table P 6.1: Illuminating power of the two sources

No. of Obs.	Make of the bulb	Distance of the bulbs from the screen for		$\frac{L_2}{L_1} = \frac{r_2^2}{r_1^2}$
		Illuminating power L_1 r_1 (cm)	Illuminating power L_2 r_2 (cm)	
1				
2				
3				
4				

b. Bulbs of different wattage but of same makes

Table P 6.1: Illuminating power of the two sources

No. of Obs.	Wattage of bulb W	Distance of the bulbs from the screen for		$\frac{L_2}{L_1} = \frac{r_2^2}{r_1^2}$
		Illuminating power L_1 r_1 (cm)	Illuminating power L_2 r_2 (cm)	
1				
2				
3				
4				

CALCULATIONS

Find the ratio of $\frac{L_2}{L_1} = \frac{r_2^2}{r_1^2}$ in each observation for both the tables.

RESULT

- Bulbs of equal wattage but different makes in decreasing order of luminosity are
 - ...
 - ...
 - ...
 - ...
- Bulbs of same make but different wattage in decreasing order of luminosities are
 - ...
 - ...
 - ...
 - ...

PRECAUTIONS

1. Lamps should be adjusted at the same height on the optical bench.
2. Index correction should be applied to each observation.
3. The reflection coefficient of the opaque portion of the screen must be unity.

SOURCES OF ERROR

1. Least count of the optical bench scale limits the accuracy of measurements.
2. It is difficult to determine exactly when the grease spot disappears, i.e., appears as bright as its surroundings.

DISCUSSION

This method can be used to compare luminous intensities of bulbs of the same power but different makes, to carry out a market survey and find out the bulb of which make is best amongst the examined.

SELF ASSESSMENT

1. What is luminous flux?
2. State the inverse square law in photometry.
3. If a 100 W bulb is placed at 40 cm on one side of the grease spot screen, where should a 60 W bulb be placed on the other side of the grease spot, so that the grease spot just disappears?
4. Do you expect the luminous flux of a bulb to be equal to the electrical power of the bulb?

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. The above method can be extended to compare the luminosities of different bulbs of unknown powers.
2. Try this experiment with a CFL bulb on one side and an incandescent bulb on the other side.

The brightness of opaque portion on the side of the standard bulb will be

$$B_1 = R_1 I_1$$

(P 6.9)

where I_1 is the intensity of illumination of the screen due to the standard bulb and R_1 is the reflection coefficient of the opaque portion. The brightness of the grease spot will be

(P 6.10)

$$B_2 = R_2 I_1 + T_2 I_2$$

where R_2 and T_2 are the reflection and the transmission coefficient, respectively of the grease spot and I_2 is the intensity of illumination of the screen due to the unknown source,

if $I_1 = I_2$, we get

(P 6.11)

$$B_2 = (R_2 + T_2) I_1 = R_1 I_1$$

Assuming the absorption coefficient to be zero. From equation P 6.9 and P 6.11, it is clear that for the two brightnesses to be equal, R_1 must be unity.

AIM

To study frequency response of (i) a capacitor (ii) an inductor (iii) LCR series circuit.

(i) Frequency response of a capacitor

APPARATUS AND MATERIAL REQUIRED

Paper or mica capacitor ($0.1 - 1.0 \mu\text{F}$), digital multimeter (DMM), carbon resistor (1000Ω) and an audio oscillator/signal generator.

DESCRIPTION OF APPARATUS

Current passing through a capacitor depends on its capacitance and the frequency of the applied sinusoidal alternating voltage. Keeping frequency fixed, variation of current (I) with voltage (V) is observed and the capacitive reactance X_c is found out from the slope of the V - I graphs. In order to measure the current, a carbon resistor R_o of the order of 1000Ω is inserted in the circuit (Fig. P 7.1) and the voltage V across it is measured with the DMM, in ac voltage mode. So the current in the circuit is $I = V_R/R_o$. Setting the oscillator at different frequencies, X_c is found for different frequencies. A graph between X_c and frequency ν is called the frequency response of the capacitor. A graph between X_c^{-1} and frequency ν is also obtained which is a straight line passing through the origin.

Note: A DMM always measures the *rms* values of ac current and voltage. It is always advised not to use the DMM in the ac current mode. These measurements are reliable only for frequencies less than 400 Hz.

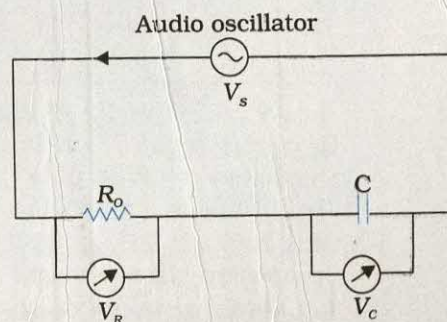


Fig. P 7.1 Measurement of the reactance of a capacitor

PROCEDURE

1. Connect the audio oscillator, carbon resistor R_o and capacitor according to the Fig. P 7.1.
2. Set the oscillator to frequency of 50 Hz and maximum amplitude. The DMM in ac voltage mode is connected across C , afterwards across R_o to measure V_c and V_R respectively. The different pairs of values of V_c and V_R are obtained by changing the amplitude of the applied voltage. The values are recorded in Table P 7.1.
3. The step 2 is repeated with frequencies 100 Hz, 150 Hz, 200 Hz, 250 Hz and 300 Hz and the corresponding values of V_c and V_R are also tabulated in Table P 7.1.

OBSERVATIONS

Table P 7.1: Measurement of X_c for different values of ν .

Sl.No.	Amplitude	Frequency, ν (Hz)		V_c (V)	V_R (V)	$I = V_R/R_o$ (A)	Slope of the V_c - I graph, X_c (Ω)
1		50	(i)				
			(ii)				
			(iii)				
			(iv)				
2		100	(i)				
--			(ii)				
			(iii)				
			(iv)				
6		300	(i)				
			(ii)				
			(iii)				
			(iv)				

CALCULATIONS AND GRAPH

For a given frequency, the values of I are plotted along x-axis and those of V_c are plotted along y-axis. The gradient ($\Delta V_c / \Delta I$) of the straight line graph (Fig. P 7.2), X_c , is the capacitive reactance and its value is calculated. The same is done for other frequencies also. The values of X_c for different frequencies are also included in Table P 7.1. The graph (Fig. P 7.3) obtained by plotting X_c along y-axis and frequency ν along x-axis, gives the frequency response of the capacitor. Now by plotting a graph with X_c^{-1} along y-axis and frequency ν along x-axis a straight line is obtained. From the slope of the straight line graph (Fig. P 7.4)

capacitance C is calculated using the formula $C = \frac{1}{2\pi} \left(\frac{p}{q} \right)$

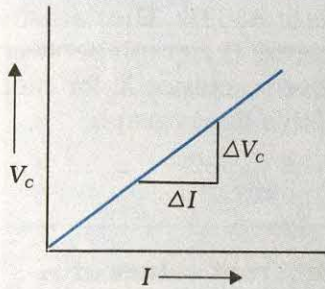


Fig. P 7.2 Variation of the voltage across the capacitor with the current flowing through it, for a given frequency

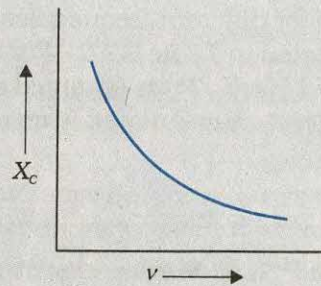


Fig. P 7.3 Variation of X_c with frequency ν .

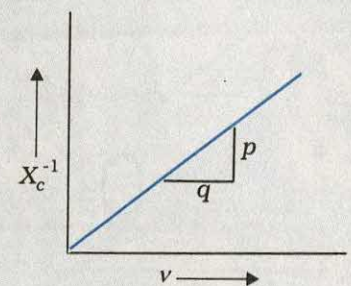


Fig. P 7.4 Variation of X_c^{-1} with frequency

(ii) Frequency response of an inductor

APPARATUS AND MATERIAL REQUIRED

An inductor (L) of inductance 0.1 H having low resistance, carbon resistor R_o (100 Ω), oscillator with low output impedance, digital multimeter (DMM).

PRINCIPLE

Current passing through an inductor depends on its inductance and frequency of the applied sinusoidal alternating voltage. Keeping frequency fixed, variation of current (I) with voltage (V) is observed and the inductive reactance is found out by drawing a straight line graph between V (along y-axis) and I (along x-axis). The slope of this graph is the inductive reactance $X_L = 2\pi\nu L$, where ν is the frequency and L is the inductance of the inductor, if the inductor is ideal i.e., its resistance r is zero. If $r \neq 0$, the impedance of the inductor is $Z_L = \sqrt{4\pi^2\nu^2 L^2 + r^2}$. Setting the oscillator at other frequencies, the inductive reactance X_L is found out for different frequencies. A graph between frequency ν and X_L , represents frequency response of inductor.

PROCEDURE

1. The connections are made according to Fig. P 7.1 by replacing capacitor C with the inductor L and changing the resistance of the resistor R_o to 100 Ω .
2. Making these connections, the values of V_L and V_R are found with

DMM for different frequencies from 50 Hz to 300 Hz. The data are tabulated in Table P 7.2. For each frequency, the graph between V_R and $I (= V_R/R_o)$ is obtained and inductive reactance X_L for each frequency is calculated from the slope of this linear graph.

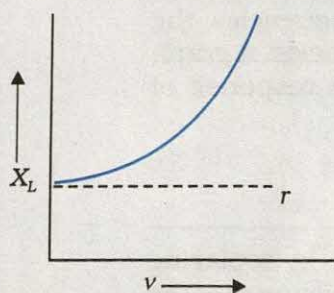
OBSERVATIONS

Table P 7. 2: Measurement of X_L for different values of ν .

Sl.No.	Amplitude	Frequency, ν (Hz)	V_L (V)	V_R (V)	$I = V_R/R_o$ (A)	Slope of the V_L - I graph, X_L (Ω)
1		50 (i) (ii) (iii) (iv)				
2		100 (i) (ii) (iii) (iv)				
6		300 (i) (ii) (iii) (iv)				

CALCULATIONS AND GRAPH

The values of X_L for different frequencies are calculated from the slope of the straight line (V - I) graphs. Now the frequency response curve for the inductor is obtained by plotting X_L along y-axis and frequency ν along x-axis (Fig. P 7.5).



The value of X_L at $\nu = 0$ Fig. P 7.5 gives the resistance r of the inductor. In order to find L , we plot a graph between Z_L^2 and ν^2 . The impedance of inductor Z_L is given as

$$Z_L^2 = 4\pi^2 \nu^2 L^2 + r^2$$

So this graph would be a straight line (Fig. P 7.6).

If the slope of the graph is m and y intercept is c , then it is clear that

$$L = \frac{1}{2\pi} \sqrt{m} \quad \text{and} \quad r = \sqrt{c}$$

Fig. P 7.5 Variation of X_L with ν

DISCUSSION

(i) If the frequency is very large then $4\pi^2\nu^2L^2 \gg r^2$, then at this high frequency range $Z_L \approx X_L$ and the $X_L - \nu$ graph is straight line. The slope of this graph at large frequency is equal to $2\pi L$, so it is possible to determine the self inductance L of the inductor from $X_L - \nu$ graph. But in order to carry out the experiment in this frequency range, DMM is not suitable, cathode ray oscilloscope (CRO) is to be used for measuring voltage. With CRO, the voltages, V_L and V_R are actually the measure of amplitudes.

(ii) If the inductor of inductance L is replaced by a carbon resistor (or any non-inductive resistor) and the experiment is repeated, then $V/I = R$ for all frequencies, so the graph between R versus ν is a straight line parallel to ν -axis (Fig. P 7.7). Resistance is independent of frequency.

(iii) Phasor diagrams

If the source voltage, V_s , in the circuit in Fig. P 7.1 is also measured along with the voltage V_C across the capacitor and the voltage V_R across the resistor R_0 and tabulated in Table P 7.1, then it can be found that

$$V_s^2 = V_C^2 + V_R^2$$

for all observations. This means as if V_C and V_R are two vectors and in the present case they are perpendicular to each other. Hence, if we draw a triangle ABC, whose length AB is proportional to V_C , length AC to V_R and length BC to V_s , then $\angle CAB = 90^\circ$.

This is true for all frequencies. This is due to the fact that V_C and V_R have different phases and in fact V_R leads V_C by 90° in phase. This is why they are called phasors.

In case of inductance also it is possible to draw phasor diagrams. Here the voltage V_L across a pure inductor (having no resistance of its own) when connected in series with a resistor R and an audio oscillator (having a small impedance), leads over V_R , the voltage across the resistor R . So,

$$V_s^2 = V_R^2 + V_L^2$$

But in reality, an inductor always has a small but finite resistance r and so if a triangle, called voltage triangle ABC is drawn and $V_s \propto BC$, $V_L \propto AB$ and $V_R \propto AC$, then the $\angle BAC$ is not 90° .

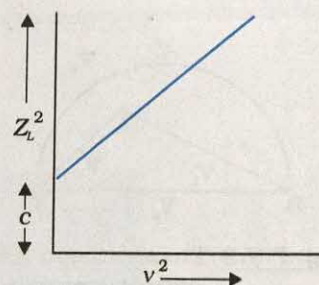


Fig. P 7.6 Variation of Z_L^2 with ν^2

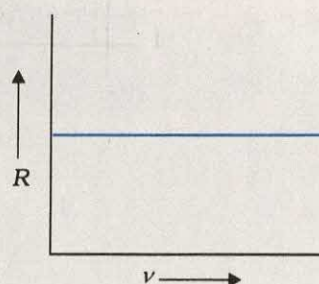


Fig. P 7.7 Variation of R with ν

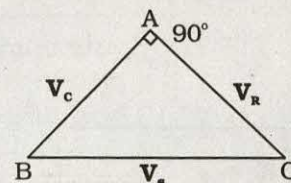


Fig. P 7.8 Phasor diagram for C-R circuit

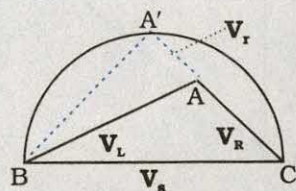


Fig. P 7.9 Phasor diagram for L-R circuit

But if we draw a semicircle with BC as the diameter and CA is produced to meet the circle at A' then CA' represents the voltage drop across the total resistance ($R+r$) in the circuit. Here $V_r \propto AA'$ and BA' represents the voltage drop across the pure inductor.

$$\text{Then, } BC^2 = BA'^2 + CA'^2$$

This can be verified by using a CRO which can measure the phase difference between the various voltages.

(iii) Frequency response of LCR series circuit

APPARATUS AND MATERIAL REQUIRED

Audio oscillator with frequency scale, a resistance box, a digital voltmeter, a $4\mu\text{F}$ capacitor, (if $4\mu\text{F}$ is not available; it can be made using a few low valued capacitors in parallel), an inductor of $\sim 100\text{ mH}$, connecting wires.

PROCEDURE

1. Connect the circuit as shown in Fig. P 7.10. The resistor $R \sim 100\ \Omega$ is connected in series with L and C .

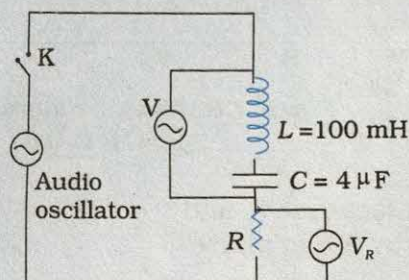


Fig. P 7.10 LCR series of the resonance circuit

2. Set the signal output to a low value say 2 V , when the switch K is kept open. Keep this setting fixed throughout the experiment so that output voltage V_c is same at all values of frequencies. (Keep the frequency below 400 Hz , otherwise digital meter readings will not be reliable).

3. Set the signal generator at some low frequency say 100 Hz and record its value.

4. Measure the voltage V_R across the known resistor R . So the current flowing in the circuit is $I = \frac{V_R}{R}$.

5. Next measure the voltage V across the LC combination (All voltages are root mean square (rms) values)

Then impedance of the LC combination is $Z = V/I$.

6. Calculate $I' = \frac{IV_0}{V}$ where V_0 is some fixed value of voltage.

Repeat steps four and five for different frequencies.

OBSERVATIONS AND CALCULATIONS

Output voltage of generator, $V_o = \dots$

Table P 7. 3: Measurement of Z for different values of ν .

Sl. No.	ν (Hz)	I (mA)	V (volt)	$I' = \frac{IV_o}{V}$ (A)	$Z = \frac{V}{I}$ (Ω)
1					
2					
...					
6					

Inductance, $L = \dots$

Capacitance, $C = \dots$

Resonant frequency, $\nu_r = \frac{1}{2\pi\sqrt{LC}} \dots \text{Hz.}$

GRAPH

Plot graphs to observe variation of (i) current I' with frequency (ii) voltage V with frequency and (iii) impedance Z with frequency. Observe the resonant frequency from the three graphs and compare their values.

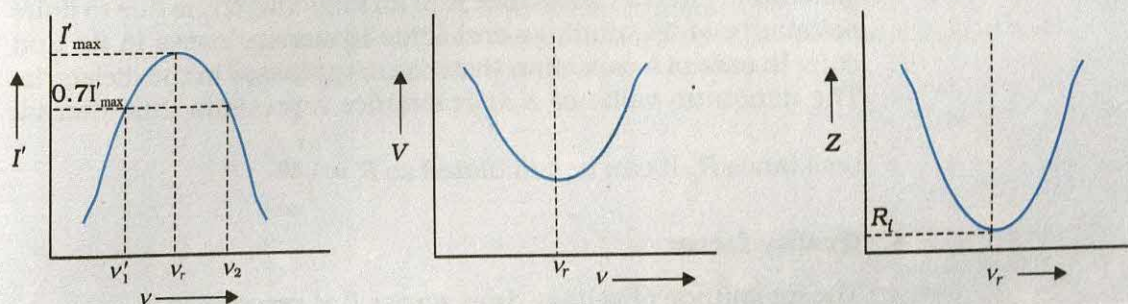


Fig. P 7.11 The nature of (a) current I' vs frequency (b) voltage V across LC combination vs frequency, (c) impedance Z of LC combination versus frequency.

RESULT

1. Resonant frequency from I' vs ν graph = ... Hz
2. Resonant frequency from V vs ν graph = ... Hz

3. Resonant frequency from Z vs ν graph = ...Hz
4. Minimum value of Z i.e., internal resistance R_i from Z versus ν graph = ... Ω (should be around $\sim 100 \Omega$)

DISCUSSION

1. Have you wondered, why to perform the experiment at low voltage? As you approach to resonant frequency ν_r , both V_L and V_C increase enormously. Therefore, it may cause damage to insulation of electrical components. This is the reason for setting up the generator at low voltage. Ensure that the capacitor and inductor are rated atleast 300 V.
2. *Phase relation between X_L and X_C* : For frequencies, quite far away from resonant frequency, individual voltages V_L and V_C may be larger than the output voltage of the oscillator and V is quite closely equal to their difference. Check up this fact at one or two frequencies by actually measuring V_L and V_C .

Obviously, it shows that inductive and capacitive reactance are opposite in character, i.e., voltage across inductor and the capacitor are in a phase opposite to each other. The ac current in circuit lags behind voltage V_L by 90° and V_C lags behind the ac current by further 90° . Hence V_L and V_C are 180° out of phase with each other.

3. *Internal resistant of resonance circuit*– Resonance in the circuit is observed when X_L and X_C are equal to each other. In case of ideal inductor and capacitor their combined reactance would be zero at resonance. It will cause an infinite current at resonance, except that it is limited by the output impedance of the signal generator. Internal resistance R_i in an inductive coil is due to finite resistance of its windings and some hysteresis losses in its iron core. In case of a capacitor, there is energy losses in the dielectric. The minimum value of X at resonance represents this internal

resistance R_i . It can be calculated as $R_i = \frac{V_{\min}}{I_{\max}}$

4. Quality factor

The magnitude of voltage drop across L at resonance is

$$V_L = X_L I_{\max} = 2\pi\nu_r L \frac{V_{\min}}{R_i}$$

$$= Q_0 V_{\min}$$

$$\text{Here } Q_0 = \frac{2\pi\nu_r L}{R_i} = \frac{1}{2\pi\nu_c R_i} \text{ is the quality factor at resonance.}$$

It is the ratio of reactance of L (or of C) to the value of X , both taken at resonant frequency ν_r . Since Q_0 is a number greater than 1, the voltage drop across C or L would be greater than $V_{\min}$, the voltage drop across L and C combine together.

Calculate the value of Q_0 , knowing the values of ν_r , R , L and C .

SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

1. Take a capacitor whose capacitance is not known. Connect it in series with an inductor of inductance L and measure their frequencies by series resonant circuit. Find the value of unknown capacitance using the equation,

$$\nu_r = 1 / 2\pi(\sqrt{LC})$$

2. Take an inductor whose inductance is not known. Repeat the above procedure to find out its value.

3. Change the resistance of LCR series circuit at three different values. In each of the three sets of observations for I as a function of frequency ν , convert values of I to I' , where I' is current that would pass keeping $V = V_0$. Then convert values of I' as percentages of

its value at resonance in that set. Plot $\frac{I}{I'}$ (in

percentage) versus frequency graph as shown in Fig. P 7.12. Compare values of Q_0 , Q_1 and Q_2 . Do you find that with smaller values of R , the resonance is sharper? Discuss your result.

4. *Half points:* Find two frequencies ν_1 and ν_2 on I' - ν graph Fig. P 7.11 (a) where the current has its value equal to 70% of the current at resonance. These frequencies are known as half points, because the power consumed in the circuit at these frequencies is half the power consumed at resonance subject to condition that constant ac potential difference is applied to the resonance circuit. Find the difference $\nu_2 - \nu_1$.

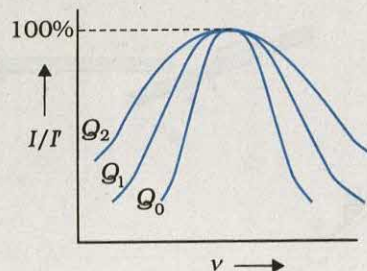


Fig. P 7.12 (I/I') versus frequency

DEMONSTRATION 1

To demonstrate that there are two kinds of charges and that like charges repel and unlike charges attract each other.

(i) Like charges repel each other

Rub a glass rod with a piece of silk cloth. Place this rod horizontally in a wire frame suspended by silk or a nylon thread as shown in Fig. D 1.1. Rub a second glass rod similarly and bring the rubbed end of this glass rod near the rubbed end of the suspended glass rod. Observe, what happens. You will find that the two glass rods repel each other. Repeat the experiment with two ebonite rods rubbed against woollen cloth. In each case you will notice that like charges repel each other. Since both the glass rods have been rubbed in a similar fashion, the two must have acquired same kind of charge. From this experiment, we conclude that similar or like charges repel each other.

(ii) Unlike charges attract each other

Rub a glass rod with a piece of silk cloth. Place it as in the previous demonstration horizontally in a wire frame suspended by a silk or nylon thread. Rub an ebonite rod with a woollen cloth and bring the rubbed end of the ebonite rod near the rubbed end of the suspended glass rod (Fig. D 1.2). Observe, what happens. You will notice that the ebonite rod attracts the glass rod. This experiment shows that unlike charges attract each other.

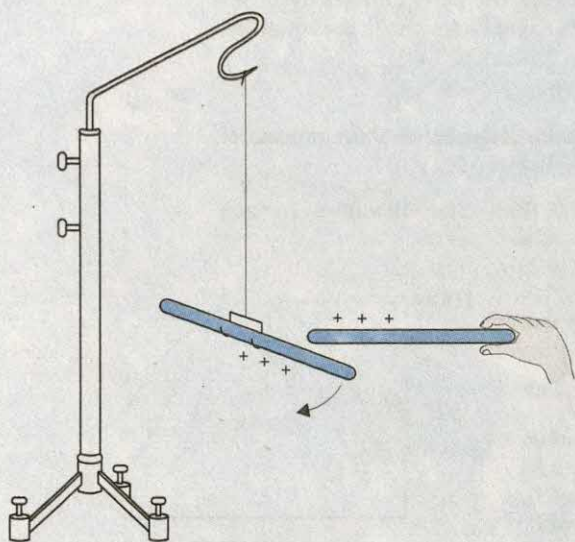


Fig. D 1.1 Like charges repel each other

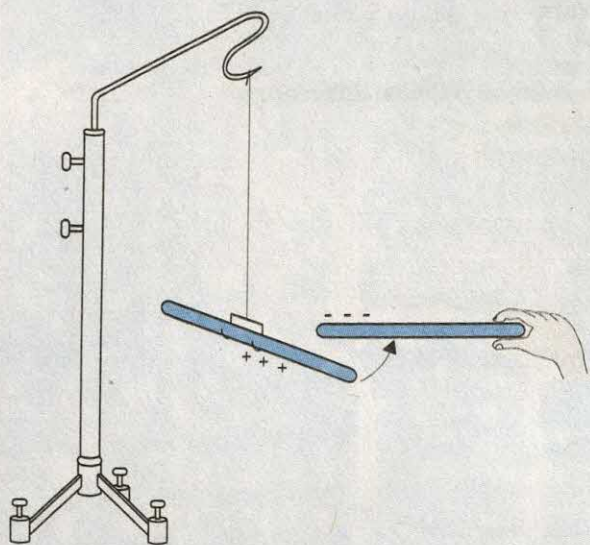


Fig. D 1.2 Unlike charges attract each other

Notes

1. The charged ebonite rod behaves differently from the charged glass rod i.e., the ebonite rod acquires a different kind of charge.
2. It is a matter of convention that the charged glass rod and all other charged bodies which behave like it are said to be positively charged.
3. Similarly, the charged ebonite rod and all other charged bodies which behave similar to it are said to be negatively charged.

DEMONSTRATION 2

To demonstrate electrostatic shielding.

Charge the electroscope either by contact or by the method of induction. The deflection in the electroscope indicates that it is charged. Bring a charged ebonite or glass rod (or a piece of thermocole) near the knob of the charged electroscope. An increase or decrease in the deflection indicates that the nature of charge on the rod is similar or opposite to that on the charged electroscope. Remove the charged rod away from the electroscope. Make sure that electroscope is still charged. If not, charge it again. Fix one end of a wire on the body of the metal can with the help of a tape. Fix other end of this wire on the ground. The metal can is now earthed. Now suspend a grounded tin can from a laboratory stand such that its open end is towards the ground. Gradually, lower the metal can in such a manner that it completely covers the knob of the charged electroscope. Take care that the metal can does not touch the knob or the body of the electroscope while it covers the knob from all sides (Fig. D 2.1). Note that the electroscope is still charged which is indicated by deflection of its leaves or the needle. Again bring a charged ebonite or glass rod near the knob of the electroscope on the outside of the metal can. Take care that the charged rod does not touch the metal can. Is there any change in deflection in the charged electroscope as was observed earlier? If not, it means that the earthed metal can is providing an electrostatic shield to the charged electroscope. Discuss your observations, especially the role of grounded metal can. The presence of a charged ebonite or glass rod near the knob of the electroscope or the outside of the *metal can* hardly affects the leaves of the electroscopes. This is electrostatic shielding.

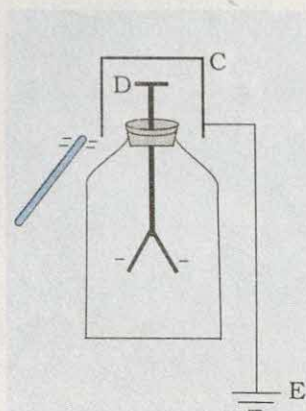


Fig. D 2.1 The earthed can C shields the disc D from the field of ebonite rod

Notes

1. You will see that a sensitive gold leaf electroscope which is supposed to measure charge accurately needs to be shielded properly so that the neighbouring charges do not affect the leaves. In order to shield the electroscope properly, it is made in a metal can C (Fig. D 2.2). In order to be able to see the leaves, the lid of the can

* An improvised electroscope can be easily made using a glass tumbler and aluminium foil. Refer to Appendix-1 for detail.

is replaced by a circular glass sheet G. Thus there is no change in the divergence of leaves if an undesirable charge A is brought in at the sides or at the back of the electroscop. The stem E holding the leaves may be insulated from the earthed can by an insulated stopper D.

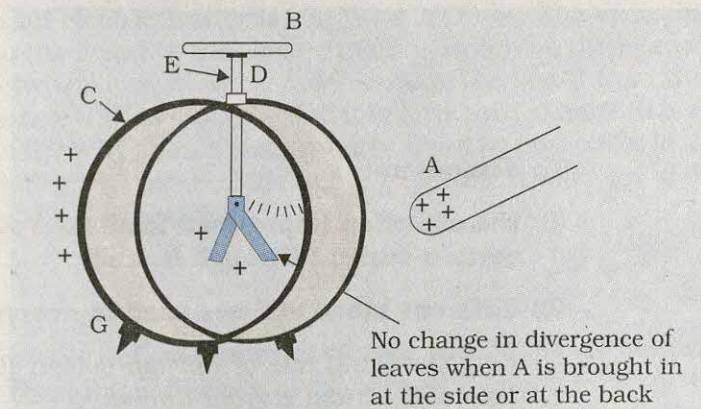


Fig. D 2.2 A shielded electroscop

To demonstrate

(i) **the use of an improvised fuse*** that melts with the flow of a certain current through it, and

(ii) **different kinds of fuses used in everyday life.**

(i) *Demonstrating use of an improvised fuse that melts with the flow of a certain current through it*

Take a small piece of suitable fuse wire (say 5 A rating) and fix it across the improvised open type fuse (see Appendix 4). Connect this electric fuse in series with a 6 V lead accumulator, a 6 V (18 W or 24 W) electric bulb (fixed in a holder), and a plug key as shown in Fig. D 3.1. Plug the key and see if the bulb glows. Observe the fuse wire. See, if it remains unaffected. Next, unplug the key to break the circuit. Short circuit the bulb by joining its terminals with a thick copper wire. Again plug the key for a short duration, the bulb would not glow this time. Does the fuse wire snap quickly? Observe carefully.

(ii) *Demonstrating use of different kinds of fuses used in everyday life*

Collect different types of fuses (i) used for different electrical appliances (ii) those used in the mains having 5 A current rating and (iii) those having 15 A current rating. Observe these and record your findings about the wire thickness. Take a switch board used with the electric mains. This switch board should have a fuse socket, a bulb holder (with a 100 W, 230 V electric bulb) and a switch in series with the fuse. It should also have a socket with the switch for connecting separately an electrical appliance, say, an electric heater in series with the fuse. Fix up a 5 A fuse wire in the socket for the fuse before plugging the switch board to the mains. Switch the electric bulb on by using the switch provided on the switch board. The bulb would glow. Observe the fuse wire.

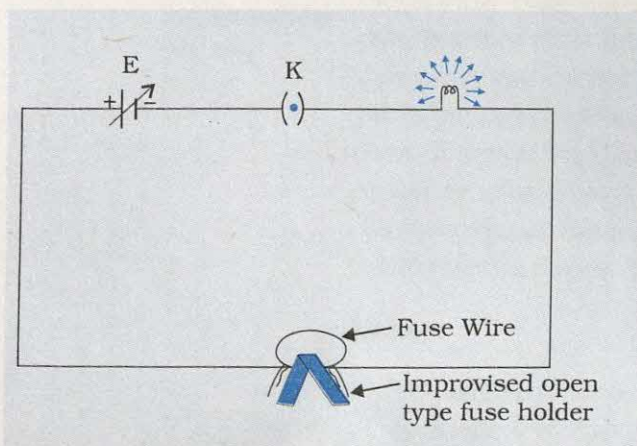


Fig. D 3.1 Circuit to demonstrate the working of a fuse

* See Appendix 4 for making an improvised open type fuse holder.

Is it intact? Switch off the bulb and unplug the board from the electric mains. Take a single strand of copper wire from the common flexible cable used as connecting lead with a table lamp and replace it in the fuse socket. Again plug the board with the mains and switch the bulb on. Does the bulb glow and keep glowing now? Unplug the board and see the effect on the improvised fuse wire. Does it change in colour? Next, connect an electric heater (1500 W or 2000 W, 230 V) to the board. Plug on the board to the electric mains. Switch on the heater. Does the improvised fuse blow off now? Unplug the board from the mains and observe the fuse. Do you find it to have melted partly (i.e. a small length of it)? Why should electric current not be passed for long duration in the circuit used in the above experiment after the 6 V bulb has been short circuited?

Notes

1. In case you have not made the improvised open type fuse holder, just hold the fuse wire ends in two crocodile clips. The open type fuse holder described in appendix 4 only makes a better demonstration.
2. To check the working status of fuse, you can check it using a resistance meter on "Continuity check". If a beep is heard then fuse is ok and if no beep is heard, fuse can be assumed to be blown off.

DEMONSTRATION 4

To demonstrate that a higher resistance is offered by distilled water and a low resistance when sodium chloride is added to it.

Take two electrodes A and B (aluminium strips or plates hanging from a wooden rod by naked copper wires will do) and dip them in a beaker about half filled with distilled water. Make a connection of the electrodes with a dry cell (1.5 V), a tapping key and a light emitting diode (LED), as shown in the circuit diagram (Fig. D 4.1). Check if the LED has been connected properly in the circuit as it conducts electric

current in one direction only. Ensure that its positive terminal is connected to the positive terminal of the cell to make it glow. For checking this, take the electrodes A and B out of water. Touch them with each other for a while and see that the LED glows. Next, place the electrodes A and B in the water and separate them with maximum gap of water. Does the LED glow now? Bring the two electrodes A and B nearer, so as to leave a small gap in water. See, if the LED glows? Add a pinch of common salt to the water while the plates are as far apart as when LED was not glowing. Does the LED glow now? Draw the conclusion on the basis of your observations.

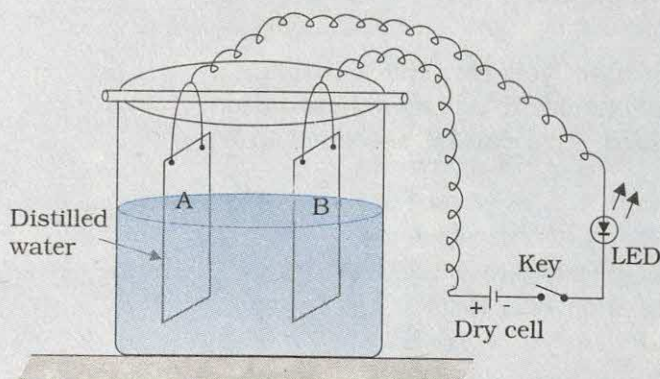


Fig. D 4.1 An arrangement to demonstrate the effect of adding salt on the electrical conductivity of distilled water

Notes

1. If you replace the LED by a multimeter which has various ranges for measuring dc current and add salt to water in equal measured steps, then you can find concentration of salt in each case and also the resistance of the solution. Do not alter the position of the two plates during the experiment. Thus you can study how the resistance varies with concentration of salt. Students may take up this experiment as project work.
2. In general, the resistivity of an electrolyte (solution of a salt whose molecules break up into anions and cations) decreases with

increasing concentration. This is due to the fact that as concentration increases, greater number of charge carrier (+ve and -ve ions) are available, which move in the electric field created between the two electrodes when a potential difference is applied between them.

3. Whereas in a metal wire, the drift of only the negative charges (electrons) contributes to the flow of current, in case of an electrolyte the drift of negative ions as well as positive ions contribute to the flow of current. It is a zig-zag motion coupled with a slow drift in the direction of the electric field.

DEMONSTRATION 5

To demonstrate the working of a lead accumulator.

Set up the electric circuit as shown in Fig. D 5.1. Connect a resistance of $1\ \Omega$ and an ammeter in series with the accumulator. Connect a voltmeter across 6 V accumulator. Circuit should not remain closed for more than one or two seconds. For this purpose use a tapping key in the circuit and not a plug key. When the tapping key is pressed, you will observe a minute fall in the voltage of the battery indicated by the voltmeter. Record voltmeter (V) and ammeter readings (I). Repeat the observation by varying the current flowing in the circuit. For this you will need to connect a rheostat in the circuit. Record your observations in the observation table and calculate internal resistance

of the accumulator $\left(r = \frac{E - V}{I} \text{ ohm} \right)$.

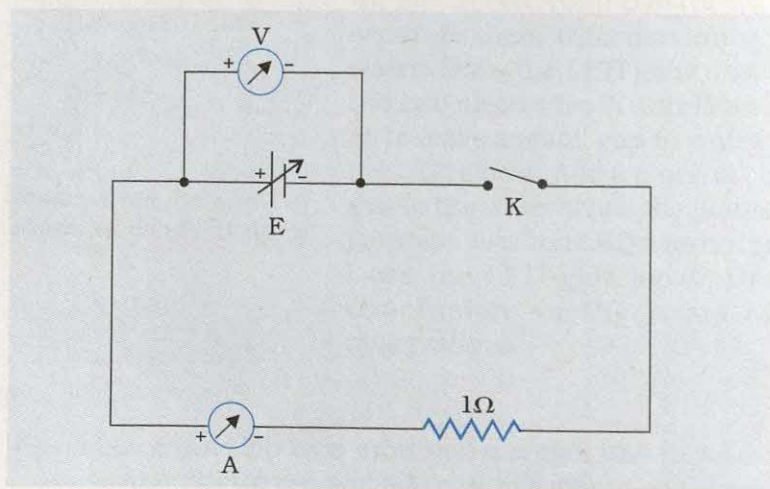


Fig. D 5.1 Circuit to demonstrate the low internal resistance of a lead accumulator

Notes

1. Examine the lead grid taken out from an old lead accumulator. Identify its positive and negative electrodes. Plates of lead oxide function as positive electrode and spongy lead functions as negative electrode.

2. A low resistance is connected in series with the 6 V accumulator in order to prevent it from damage. It also minimises heating up of connecting wires which may cause a burn.
3. Never short circuit the battery, as life of the battery is greatly reduced. Some equipments like an ammeter of smaller range may get damaged by the heavy current produced.
4. It should be recharged when voltage of any cell in it falls to 1.85 V from the normal range of 2.0 V. For this purpose it should be connected to battery charger as shown in Fig. D 5.2.

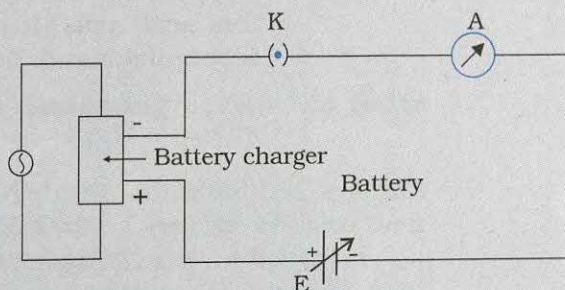
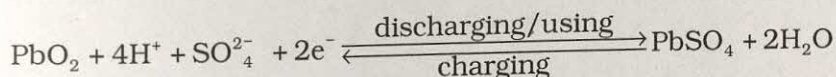


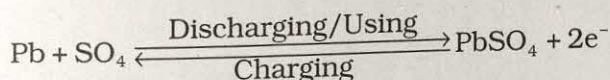
Fig. D 5.2 Circuit for charging a battery with the help of a battery charger

5. The chemical reaction during its discharging/use and during charging are as follows:

Positive electrode



Negative electrode



Thus PbSO_4 is formed on both electrodes during use and an over used cell is said to become "sulphated". Also, formation of water and consumption of sulphuric acid and consequent decrease in density of the acid takes place.

6. Effect of over charging a battery is loss of water by electrolysis and hence the need to check its water level continually and bring it up by adding distilled water. This process is sometimes referred to as *topping up* with distilled water.
7. Measuring emf of an acid accumulator is not the best method to test whether it needs recharging. This is because ordinary voltmeters may not measure voltage quite accurately, a voltage of 1.85 V may be read as 1.9 V.

Density of the acid inside is a much better indicator. In a charged accumulator, it is 1.26 kg/L. When it falls to 1.20 kg/L, the

accumulator needs to be recharged. Measure density of acid inside the accumulator by the special hydrometer made for this purpose and infer the condition of that accumulator. The density should be measured only after topping it up with distilled water.

8. Sulphuric acid for a new battery is made by pouring slowly the concentrated acid into distilled water, 3-times its volume. When this acid cools, it is filled in the new lead acid battery/lead accumulator and then the battery is charged overnight.

DEMONSTRATION

6

To demonstrate that a current measuring device has finite non-zero resistance.

Make a circuit using a cell, key, rheostat, ammeter and a digital multimeter (DMM) as shown in Fig. D 6.1. Close the key and then adjust the rheostat so that a current of the order of 1 A flows through the ammeter. Observe the voltage drop (V) across the ammeter with the voltmeter DMM in dc mV range. Record your observations and find the resistance of the ammeter by the ratio of the voltage drop V to

the ammeter reading, $I \left(R = \frac{V}{I} \text{ ohm} \right)$. Repeat the procedure for different ammeter readings and calculate mean value of the resistance.

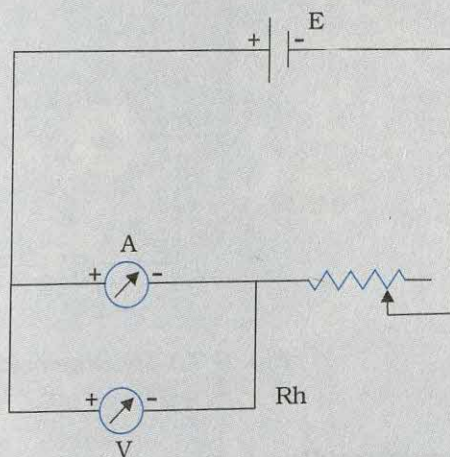


Fig. D 6.1 Measurement of the resistance of an ammeter

Notes

1. Though it is commonly said that ammeters are connected in series in a circuit as they have no resistance. This is an ideal case, but in practice this is not exactly so. An ammeter has finite non-zero resistance.
2. The above experiment can be demonstrated by using a milliammeter (having resistance of the order of 10Ω) or a microammeter (having resistance of the order of $k \Omega$) also.

DEMONSTRATION 7

To demonstrate that a voltage measuring device has non-infinite resistance.

Make circuit as shown in Fig. D 7.1 using a cell, a key, a voltmeter and two carbon resistors of $10\text{ k}\Omega$ each. Now close the key and observe the voltmeter reading by connecting it across one of the two carbon resistors. Calculate the resistance of the voltmeter by using Eq. D 7.1. Repeat the experiment using more cells varying the value of E .

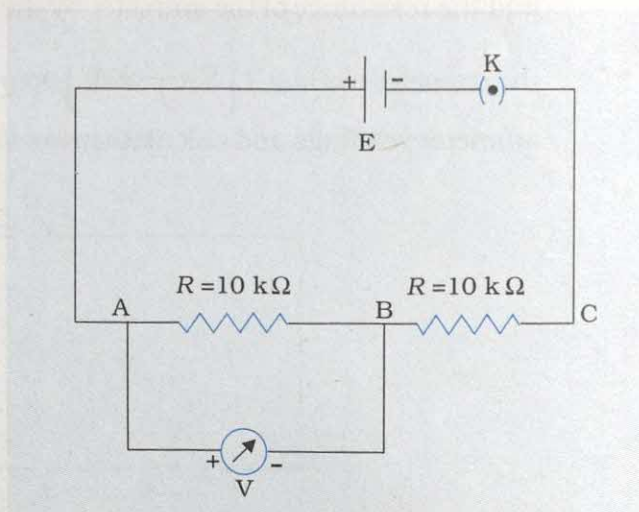


Fig. D 7.1 Measurement of resistance of a voltmeter

Notes

It is commonly said that as voltmeter is connected in parallel, its resistance is infinitely large. But that is not so in practice as this is an ideal case. Each voltmeter, particularly the analog meters have non-infinite resistance.

Denoting resistance of the voltmeter by R_V and current by I , the circuit (Fig. D 7.1) is analysed as follows:

$$I = \left(\frac{E}{R + \frac{RR_V}{R + R_V}} \right)$$

Hence, the voltmeter reading i.e., the voltage across AB

$$V = \left(\frac{E}{R + \frac{RR_v}{R + R_v}} \right) \frac{RR_v}{R + R_v} = \frac{ER_v}{R + 2R_v}$$

$$R_v = \frac{VR}{E - 2V}$$

(D 7.1)

If R_v approaches infinity then from equation D 7.1, $V = \frac{E}{2}$. In reality,

this is much less than $\frac{E}{2}$.

DEMONSTRATION 8

To demonstrate the magnetic field lines with the help of iron filings.

Take a strong bar magnet of size 7.5 cm or 10 cm. Place the magnet under the glass sheet at the centre. Adjust the glass sheet horizontally by supporting it with four wooden blocks and by checking it with a spirit level. Sprinkle fine dry iron filings around it on the glass sheet. Now gently tap the glass sheet several times. Observe what happens. You will find that iron filings arrange themselves in a regular pattern as shown in Fig. D 8.1. This happens because under the influence of magnetic field, iron particles behave like small magnets and form long chains along the lines of the magnetic field. Therefore they align themselves along the magnetic field lines. Note that the long chains of the iron particles start from the north pole of the magnet, end at the south pole and avoid contact with middle portion. Observe the pattern of lines carefully and try to infer the relation between the gap of two adjacent lines and strength of magnetic field in this gap. Report what inference do you draw from it.

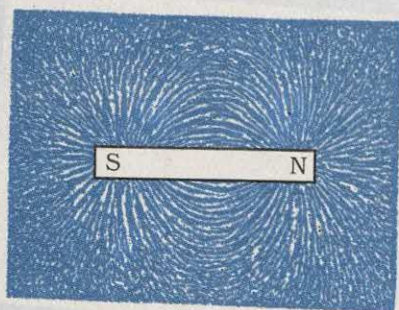


Fig. D 8.1 Iron filings near a bar magnet align themselves along the magnetic field lines

Notes

1. The pattern of iron filings on glass sheet may be fixed by spraying clear lacquer paint on the glass sheet. Let it become dry. It can be put up as a permanent display.
2. Suppose you perform the experiment with a magnetic compass as follows. You place the magnet below a thin glass plate (or a plane sheet of thin plywood or thick cardboard). Fix a paper on the plate and adjust it horizontal with a spirit level. Then plot the magnetic field lines with the magnetic compass. What kind of lines do you expect to get? Does any line make a complete loop through the magnet? You may refer to *Laboratory Manual Science, Class X, (NCERT, 2008 Experiment 52, pp.217-220)* for an elementary method.

DEMONSTRATION

9

To study the effect produced on magnetic field pattern by bringing various materials in the surrounding space of a bar magnet.

PROCEDURE

Take a drawing board and fix a plane sheet of paper over it using molten wax of a candle. Draw two lines perpendicular to each other say NS and EW at the centre of the sheet. Place a magnetic compass at the centre of the sheet and rotate the drawing board till magnetic needle of the compass box exactly overlaps the line NS. In this case, the needle will point along the north-south direction. During this process, tap the board gently to ensure that friction between the needle and its pivot is minimised and that it rotates freely. Draw an outline of the drawing board with a chalk. Position of the board should not be disturbed throughout the experiment. Place the magnet symmetrically in the middle of the line NS so that axis of the magnet is along the north-south direction and its north pole points towards north. In this situation magnetic axis is also coinciding with one of the lines drawn on the paper. In this way you have placed the magnet in magnetic meridian. With the help of magnetic compass, map its magnetic field lines. Find the points where horizontal magnetic field of the earth balances the magnetic field of the magnet. These are the neutral points. You get a pattern similar to that obtained in Demonstration 8. Put all magnets and magnetic substances away from the drawing board while demonstrating this experiment. Now replace the drawing paper, place the magnet in same position and place a bar of soft iron at some distance from the magnet, say near north pole of the magnet. Again map the magnetic field of the magnet. What is the pattern like now? You observe that it is quite different from the pattern of magnet alone. Many lines tend to pass through or close to the soft iron bar. Neutral points also move away from the magnet. Test the polarity at the ends of the iron bar with the help of a compass. You will find that it has become a magnet. Repeat the experiment with a bar of aluminium, copper, nickel, chromium and plastic material. Observe the pattern of lines.

Notes

1. The end of the iron bar where many lines starting from north pole of the magnet entering the iron bar, behaves as the south pole and the other end behaves as the north pole. Thus the iron bar becomes an induced magnet.
2. You will observe that patterns of magnetic field lines due to a bar magnet are not altered by the presence of copper, aluminium and plastic bars. These materials do not become induced magnet.
3. If you repeat the above experiment using a bar of nickel or cobalt, you will find that pattern of lines is altered, though not so much as in the case of the soft iron bar.
4. Materials by which the pattern of magnetic field lines is altered are called ferromagnetic materials.
5. If a magnetised needle is suspended to swing freely in all planes, it sets itself pointing to the Earth's magnetic North and South poles, at an angle to the horizontal. The vertical plane through the axis of such a needle is termed the magnetic meridian.

DEMONSTRATION 10

To show that the earth's magnetic field has both vertical and horizontal components.

You need a dip needle and a compass needle to demonstrate this experiment.

Dip needle

Dip needle is a compass needle free to rotate in a vertical plane. Its horizontal axle about which it rotates, passes through its centre of gravity. Thus gravitational force has no tendency to keep it in any preferred direction. The needle and its frame can rotate about a vertical axis so that its vertical plane of rotation can be set in any direction (Fig. D 10.1). A 90° circular scale is also attached to the frame on which you can observe at what angle to the horizontal the needle comes into equilibrium.

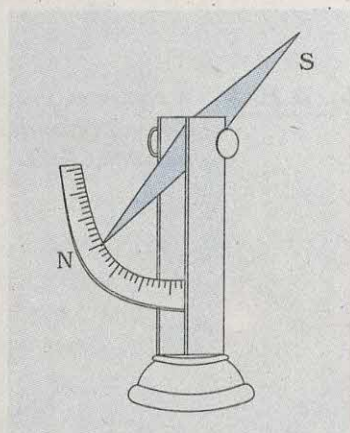


Fig. D 10.1 The dip needle

Vertical component

Keeping the vertical plane of rotation of the dip needle in north-south direction (i.e. in magnetic meridian), observe the reading of the needle on the circular scale. Repeat the above observation keeping the plane of rotation at various angles to the magnetic meridian. Observe the direction of plane of rotation of the needle when the deflection in the needle is largest i.e. 90° and the needle becomes vertical [Fig. D 10.2(a)]. Is it along east-west direction? Now, rotate the plane of needle in magnetic meridian. Observe the reading on the circular scale. In this position the horizontal component of earth's magnetic field is fully effective and the needle points in the direction of the resultant magnetic field. The reading on

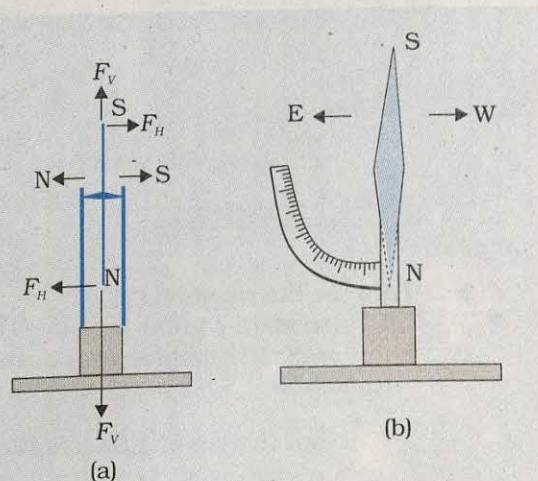


Fig. D 10.2 (a), (b) Dip needle becomes vertical when its plane is in East-West direction

the circular scale in this position gives angle of dip (Fig. D 10.4).

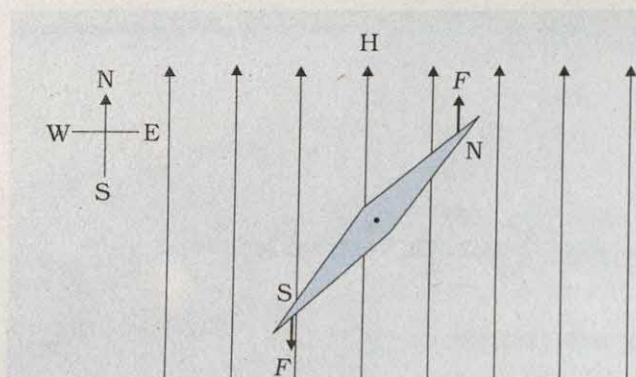


Fig. D 10.3 A compass needle experiences forces F - F in horizontal plane in the earth's magnetic field

Horizontal component

Take a compass needle. Place it horizontally on a pointed support so that it is free to rotate in a horizontal plane. You find that it comes into equilibrium along north-south direction only. If you leave it in any other position, it moves to north-south direction. It implies that forces are acting on its poles as shown in Fig. D 10.3. Earth's magnetic field is capable of applying a force in a horizontal plane towards north direction on the north pole of the compass needle and an equal opposite force on the south pole. Hence earth's magnetic field has a horizontal component.

Notes

1. When the dip needle reads 90° , the vertical component of earth's magnetic field pulls the north pole of needle downwards and pushes the south pole upwards. The horizontal component is ineffective because forces F applied by it on the poles of the magnetic needle are perpendicular to the plane of rotation of the needle as shown in Fig. D 10.2(b).
2. The north direction indicated by the compass is usually not the geographic north direction. The angle between the geographic north and the north shown by a compass needle is called the magnetic declination or simply declination. Only if you know this angle, you can find geographic north direction with the help of a compass.
3. The vertical component of earth's magnetic field and angle of dip can also be demonstrated with the help of a dip circle which is a more elaborate instrument.

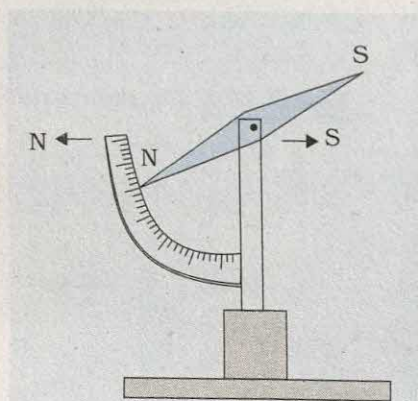


Fig. D 10.4 In the magnetic meridian, the dip reads the angle of dip

DEMONSTRATION 11

To demonstrate repulsion/attraction between two conductors carrying current in opposite/same direction.

You need following apparatus and materials to demonstrate this experiment:

A source of dc voltage (or battery eliminator) (6 V, 3 A), 2 m copper wire (18 or 20 SWG), a wooden board (8" × 12"), 2 wooden supports (1.5" × 1.5" × 12"), connecting wires, 4-5 nails, 6 screws, two thin metal strips (1.5" × 3"), a key and a low resistance rheostat (~ 10 Ω).

Figure (D 11.1) shows two long parallel conductors a (AB) and b (XY) separated by a distance d carrying current I_a and I_b respectively. According to right hand rule the direction of the magnetic field due to current in conductor AB acting on conductor XY is downward. Its

magnitude is given from Ampere's circuital law, $B_a = \frac{\mu_o I_a}{2\pi d}$. The

conductor b carrying a current I_b will experience a sideways force due to the field B_a . The direction of this force is towards the conductor a (Fig. D 11.2). The magnitude of this force on a segment L of b due to a is,

$$F_{ba} = I_b L B_a$$

(D 11.1)

In other words, we can say that parallel conductors carrying current in the same direction attract each other with a force

$$F_{ba} = \frac{\mu_o I_a I_b L}{2\pi d}$$

(D 11.2)

Similarly, we can establish that parallel conductors carrying current in opposite direction repel each other.

Fix both the wooden supports in vertical position near the edge of the wooden board using nails or screws. Experimental set up is shown in Fig. D 11.2. Fix metal strips (1.5" × 3") at the top of these supports using screw or nail. Take about 80-85 cm long thick copper wire and bend it as shown in Fig. D 11.3. Using sand paper or a file, make the ends of the wire sharp tipped. Now place this bent wire on pillar tops

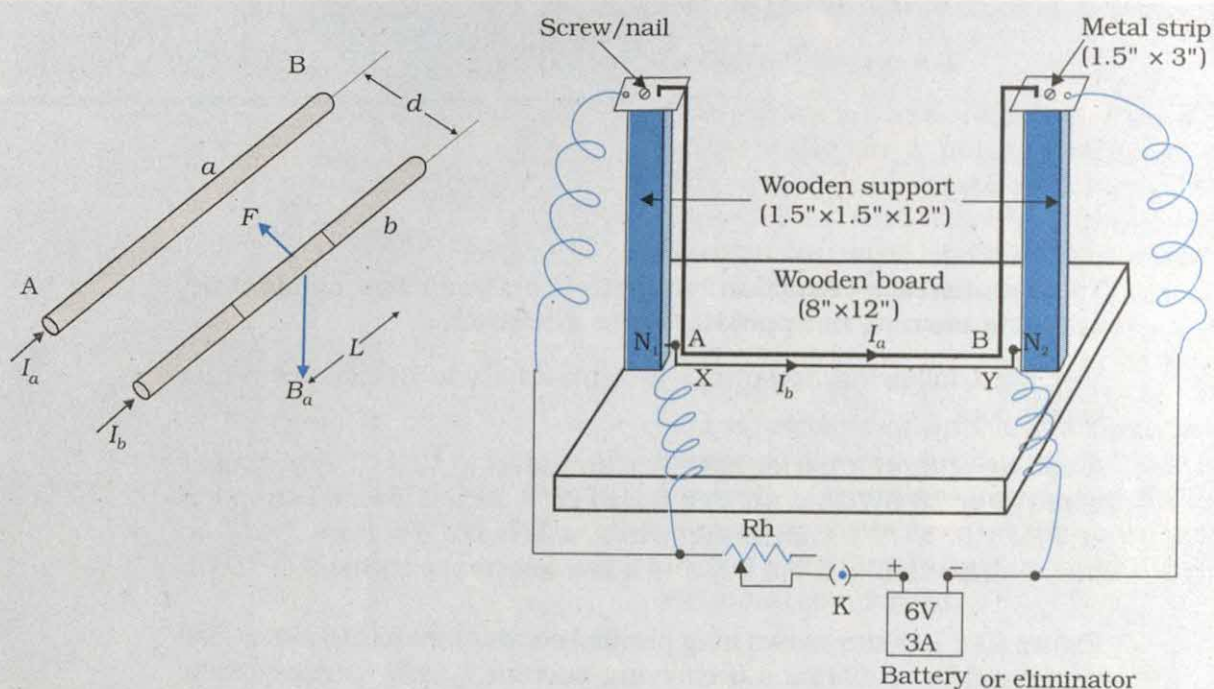


Fig. D 11.1 Two long straight parallel conductors carrying steady currents I_a and I_b and separated by a distance d . B_a is the magnetic field set up by conductor a at conductor b .

Fig. D 11.2 Repulsion/attraction between two conductors carrying current in opposite/same direction respectively

as shown in Fig. D 11.2. Fix two straight nails N_1 and N_2 close to the lower portion AB of suspended $\sqcap$ shape wire. Fix tightly a thick copper wire XY between the nails N_1 and N_2 such that the separation between AB and XY is about 1 or 2 mm. Now make electrical connections using a rheostat, a key and a battery as shown in Fig. D 11.2. When the key K is plugged, the current in the wires AB and XY flows in the same direction. We observe that wire segment AB is attracted towards the wire XY. On reversing the connections of the fixed wire XY we observe that the suspended wire segment AB is repelled away from the wire. The activity can be repeated by (i) changing the length of XY, (ii) by changing the strength of the current. We observe that currents flowing in the same direction attract each other and oppositely directed current repel each other.

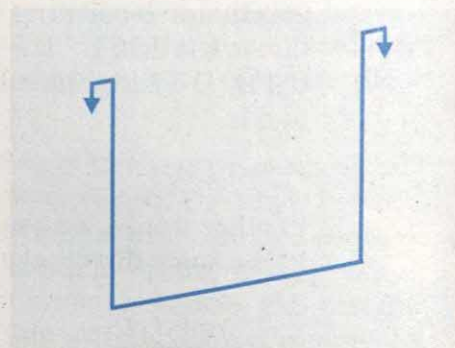


Fig. D 11.3 $\sqcap$ shaped copper wire

Notes

1. If F_{ba} represent the magnitude of the force F_{ba} per unit length, then from Eq. E 11.2.

$$F_{ba} = \frac{\mu_o I_a I_b}{2\pi d}$$

(D 11.3)

Eq. 11.3 is used to define the SI unit of electric current, ampere (A), which is one of the seven base units.

2. Care should be taken not to pass current for a longer period as it may heat the wire.

DEMONSTRATION 12

To demonstrate the production of induced emf in a coil due to the movement of (i) a magnet towards and away from it (ii) similar coil carrying current towards and away from it.

- (i) *Demonstrating production of induced emf in a coil due to the movement of a magnet towards and away from it*

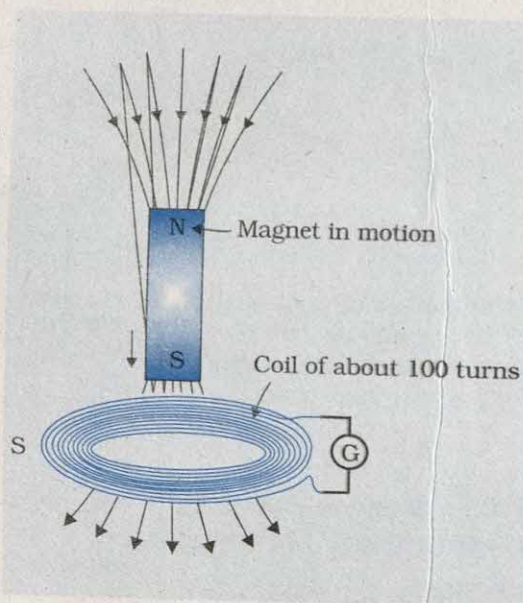


Fig. D 12.1 Magnet in motion produces an induced emf in coil S

Connect the two ends of the coil of 100 turns with the terminals of a sensitive galvanometer as shown in Fig. D 12.1. Hold the magnet in your hand and bring it towards the coil with a large speed. It may be inserted right into the coil. You will observe some deflection of the galvanometer needle, which is a measure of the induced current that flows due to an induced emf generated in the coil. Now move the magnet away from the coil with roughly the same speed. You will observe the same deflection, but now in opposite direction. In the former case, the magnetic flux passing through the coil was increasing while in the latter case, it was decreasing. Note also that the deflection is observed only when the magnet is in motion. It shows that the induced current flows as long as the flux is changing. Repeat the above steps by varying the speed of the magnet. Observe and record your observations.

You will find that when you move the magnet towards the coil, the magnetic flux ϕ_B passing through the coil increases and when you move it away from the coil, magnetic flux decreases. If you repeat the demonstration by moving the magnet faster, you will observe greater deflection in each case. It shows that higher the rate of variation of the magnetic flux, the greater is the induced emf in the coil. This is a qualitative demonstration of the Faraday's law which states that the induced emf is directly proportional to the rate of change of magnetic flux through the circuit.

Notes

1. In the case of closely wound coil of N turns, change of magnetic flux associated with each turn, is the same. Therefore, the

expression for the total induced emf is given by $E = -\frac{Nd\phi_B}{dt}$.

2. DCC wire has two layers of cotton thread wound on it for insulation and is quite convenient for low voltage experiments in the laboratory.
- (ii) *Demonstrating production of induced emf in a coil due to the movement of similar coil carrying current towards and away from it.*

Take the coil S used in Demonstration 12 (i) above and connect it with the galvanometer. Take another coil P of same diameter having 50 number of turns. Connect it with a battery and a rheostat through a key as shown in Fig. D 12.2. Move this coil towards or away from the coil S as the magnet was moved in Demonstration 12 (i). The coil P acts as a magnet due to the current flowing in it. Observe a deflection in the galvanometer. This is an evidence of production of induced emf in coil S. Note and

observe that the deflection in the galvanometer is larger when coil P moves faster towards coil S. Without changing the position of P change the current flowing through it using the rheostat. You will observe change in the galvanometer deflection as the magnitude of current through the coil changes. Now place the coil P on the coil S, separated by an insulator like a glass plate or cardboard sheet. Do not move coil P. Observe the deflection in the galvanometer connected to S as you switch on the current in P. Switch off the current in P. You will observe that direction of deflection in the galvanometer is opposite. Now allow a constant current to pass through the coil P. As current is not changed, magnetic field is also not changed. Coil P is just above S, so almost all the lines of magnetic field of P pass through S. Slide P on the glass plate so that common area of the two coils decreases. Observe deflection in galvanometer in the same direction as that when current was switched off in P. Next increase the common area of the coils and observe deflection in the galvanometer. It is in the same direction as that when current was switched on in P.

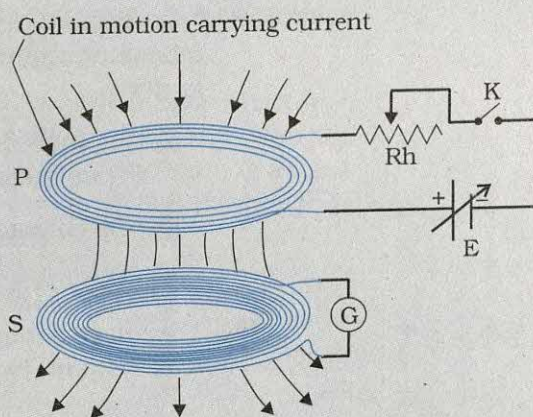


Fig. D 12.2 Current carrying coil in motion produces an induced emf in coil S

Notes

1. When the current is varying, it produces a changing magnetic field, which in its turn induces an emf in the conductors through which the magnetic field lines pass.
2. From the above observations it is clear that motion of the coil or magnet is not the important factor. It is the change of magnetic flux produced by the coil P in the area occupied by S which causes induced emf in the coil S.
3. It is the magnetic flux produced by P and passing through S, whose change causes induced emf in S, whether the change is done
 - (i) by motion of P which changes the field strength in S and thus magnetic flux through the coil S;
 - (ii) by change of current in P; or
 - (iii) by change of area of P facing the coils.
4. The above demonstration can be repeated by connecting battery, rheostat and key to the coil S and galvanometer to the coil P.

DEMONSTRATION 13

To demonstrate that a large emf is induced when direct current is switched off in an inductive circuit.

Make a circuit as shown in Fig. D 13.1. N is a neon lamp fitted into holder across the two terminals of the coil connected in series with the battery. Close the key K and observe that the neon lamp does not light up. Now open the key K. The lamp is seen to flash indicating that in the inductor L, a large induced emf has been generated. The induced emf tends to maintain the flow of current through the coil after the source of emf has been switched off.

Notes

1. The back emf in an inductive coil cannot exceed the emf of the battery when the current is switched on, because the resultant of the two must pass (conventional) current from positive terminal of the battery. However when dc is switched off, the situation is different. A large emf is generated in the inductor L tending to maintain the flow of current through the coil and lamp is seen to flash.
2. According to Faraday's law of electromagnetic induction, this large induced emf is generated due to the fact that when key is opened, current through the battery instantly stops. Thus, rate of decrease of magnetic flux in the coil is very large and a large emf is induced, which passes a pulse of electric current in the lamp.
3. After switching on the circuit, neon lamp does not glow. This is because the striking voltage for neon lamp (about 150 V) is considerably larger than the modest 2 to 3 V, which battery E is capable of supplying.
4. When the source of emf (the battery) has been cut off, where does the energy which flashes the neon bulb come from? It comes from the magnetic field associated with the coil L with current passing through it. Thus this experiment also vividly demonstrates that a magnetic field contains energy.

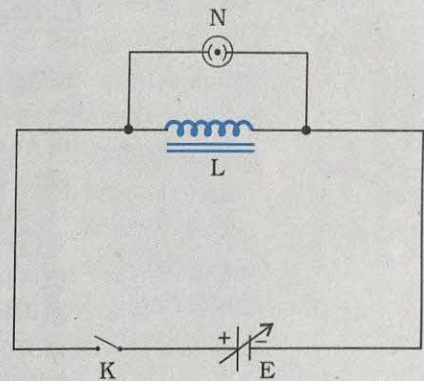


Fig. D 13.1 When current in the circuit is stopped then only, the neon bulb N flashes.

5. The phenomenon of induced emf existing in the same coil in which the changing current passes is called self inductance. Mathematically, the self inductance (L) of a coil is defined by the equation

$$E = -L \frac{dI}{dt}$$

where E is induced emf and $\frac{dI}{dt}$ is the rate of change of current

passing through the coil. Negative sign in the above equation only indicates that the direction of induced emf is opposite to the change in current and tends to maintain the current constant.

6. Mechanical analogy of self inductance:

The above equation is quite similar to the following equation in mechanics. Force exerted by a moving object on any object due

to its inertia $= -m \frac{dv}{dt}$, where m is mass and $\frac{dv}{dt}$ is rate of change

of velocity i.e. acceleration of the body. Here too, the negative sign indicates only that the direction of force is opposite to the change in velocity and tries to maintain the velocity constant. Thus, the role of L in an electric system is similar to that of mass, in a mechanical system. For example, switching on a dc current in the coil is analogous to accelerating a hammer. Therefore, switching off this dc current is analogous to the hammer striking a nail when its motion is instantly stopped and it applies a large force on the nail.

DEMONSTRATION 14

To demonstrate (i) the principle of transformer by winding primary and secondary on a steel rod; and (ii) removal of eddy currents by using laminated core.

- (i) *Demonstrating the principle of transformer by winding primary and secondary on a steel rod*

Take a soft iron rod of 15 cm length and 1.3 cm diameter. Wrap thick paper on it. Wind a coil P of enamelled copper wire (22 SWG or 20 SWG)* with 200 turns. Wind another coil S of thick enamelled copper wire (18 SWG or 16 SWG) P with 50 turns as shown in Fig. D 14.1. Both coils are wound over same length of the rod, so that almost the entire flux produced by current in one is linked to the other. Connect the coil P with 6 V ac supply obtained from a step down transformer. Connect the coil S with an ac voltmeter (0-10 V). Connect an identical ac voltmeter across coil P also. Switch on the current in P and note the voltage V_P and V_S across the two coils. Find the ratio of V_P to V_S . You find that this ratio is equal to the ratio of the number of turns in the coil P to that in the coil S, i.e.,

$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

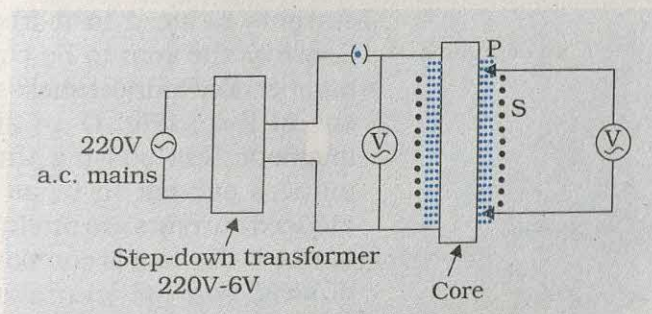


Fig. D 14.1 A simple transformer made by winding two coils on an 'I' shaped iron core

* See Table D₅.6, p 289

Notes

1. The coil P (on which ac voltage is applied) is called the primary and coil S (in which ac is induced) is called the secondary.
2. Since coil S is placed very close to the coil P (they are not connected to each other, rather they are separated by insulating enamel), the power in the primary is transferred into the secondary through mutual induction.
3. As it is clear from the above equation, by appropriate choice of the turn ratio i.e. $\frac{N_P}{N_S}$, we can obtain a higher voltage or lower voltage in S compared to that in P.
4. It should be noted that a steady dc voltage cannot be stepped up or stepped down by a transformer, because a steady dc current does not produce changing magnetic flux and therefore cannot produce induced voltage.
5. Transformer is an important application of mutual induction. Depending upon the ratio of turns in the two coils, a transformer can step down or step up ac voltage.

(ii) Demonstrating removal of eddy currents by using laminated core

In the above demonstration, connect P to 6 V ac for some time continuously and feel the hotness of the core and coil by hand. You will find that the core soon gets hot, while the windings of copper wire are comparatively cooler. Switch off the transformer when it is rather too hot to touch, otherwise the enamel coating of copper wire may burn out. The core gets hot due to eddy currents induced in it (resistive heating). Consider the core to be composed of large number of cylindrical shells and consider any one of them (Fig. D 14.2). The changing magnetic flux passing through this shell induces current in it, as in a coil. Such induced currents are produced in every shell of which the core is composed. Now instead of solid iron rod you take laminated core consisting of thin soft iron wires insulated from each other by an enamel coat and pressed together. Repeat the above demonstration using this core. You will find that the core made of wires does get hot, but much more slowly.

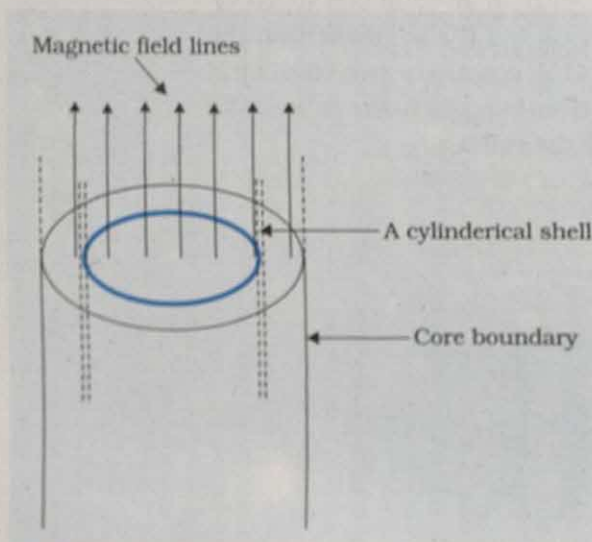


Fig. D 14.2 Changing magnetic flux within the core produces induced emf around any cylindrical shell within the core

Notes

1. Insulating enamel amongst the soft iron wires reduces eddy current considerably as the current cannot flow from one wire to another. However, there are some eddy currents within each wire too.
2. It may be mentioned that this kind of core becomes useless for higher frequencies.

Making a simple electroscope and using it to detect charges on bodies

Bend a metal wire with a knob at one end (you can make such a knob by twisting the wire several times at end A) into the shape shown in Fig. A_x1(a). Take about 8 cm long and 1/2 cm broad strip of thin aluminium foil. Fold it round the middle. Gently place it on the horizontal arm B of the wire. Take a tall glass jar or a tumbler. Stick two aluminium foils C and D, 2 cm broad and 10 cm long, on opposite sides of the glass tumbler. Gently lower the copper wire having the folded aluminium strip on its arm B. Orientation of the wire must be such that C faces one half of the folded aluminium strip and D faces the other half [Fig. A_x1(b)]. E is a cardboard disc to support the wire. This is your electroscope.

In order to test whether a given body is charged or not the body (say a glass rod) is brought near the electroscope and made to touch its end A. If the body is charged you will notice the aluminium strip will diverge.

With the help of this electroscope, you can show that bodies acquire charge on

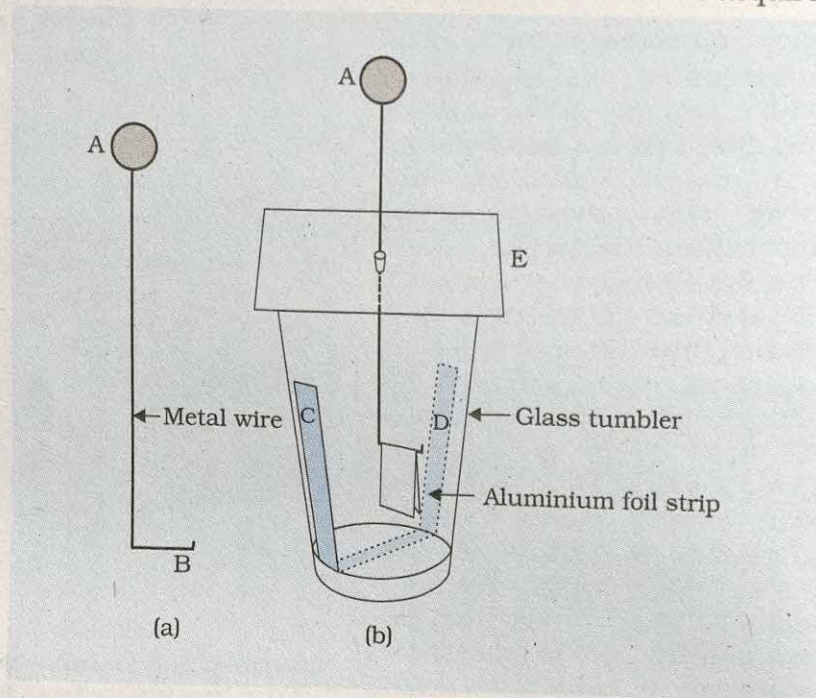


Fig. A_x 1(a),(b) An improvised aluminium foil electroscope

rubbing. You can also show that during the process of rubbing, the two bodies involved in rubbing acquire opposite kinds of charges.

Guideline for making a mechanical model of "Electron Drift" in a metal wire

Take a straight aluminium channel AB, about 3 cm wide and 50 cm long [Fig. A_x 2(a)]. The atoms/ions(+ve) are to be represented by fixing the smallest size of bicycle steel balls (about 3 mm diameter) and the free electrons by the small beads (used in electrostat machines) free to move when the channel is given a slant. The steel balls are to be fixed after putting, carefully, small quantity of a strong adhesive, (say araldite) on each ball just enough to stick the lower tip of the ball to the aluminium surface. Adhesive should not provide any resistance to the drifting tiny beads when these collide with the steel balls. Therefore, before putting the adhesive, points have to be marked all along the channel by repeating the pattern of a crystal lattice network [Fig. A_x 2(b)]. This pattern can be achieved more accurately by sticking a strip of graph paper equal in size to that of the channel. Mutual gap among balls should be about twice the size of the beads representing electrons.

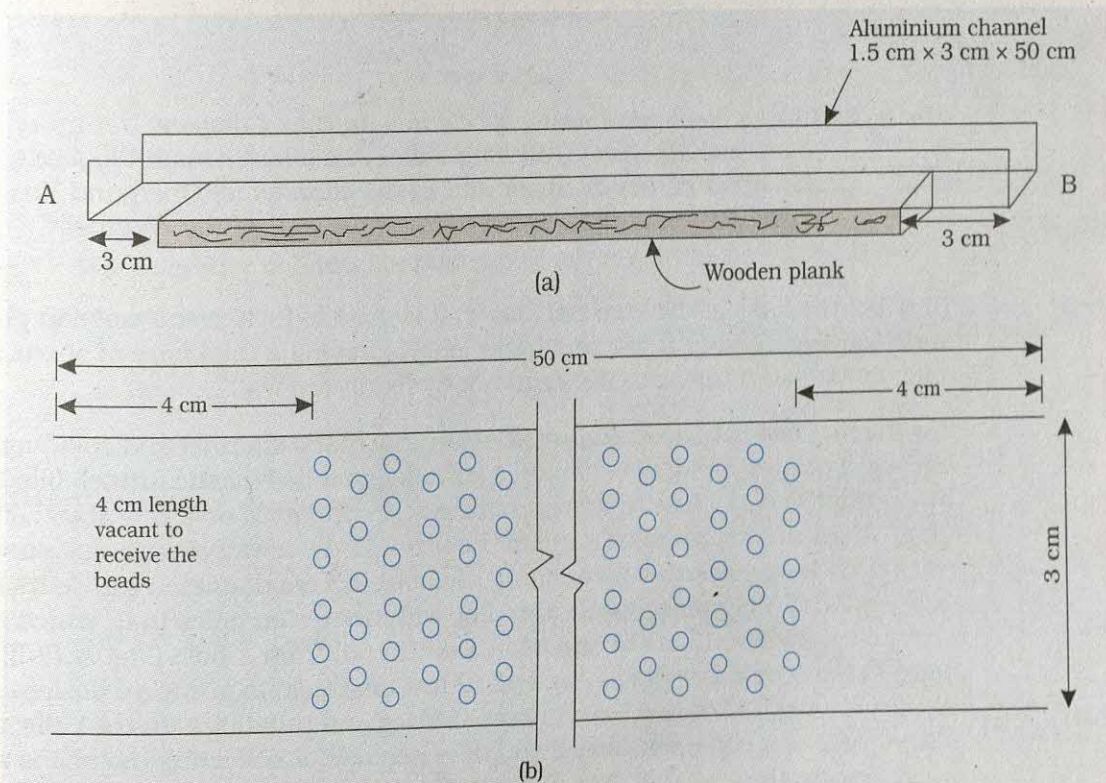


Fig. A_x 2 Making mechanical model of "electron drift" (a) Fixing up aluminium channel on a wooden plank (b) Fixing ball bearings on the channel in the pattern of face-centred crystal lattice.

Note : This figure is not to scale.

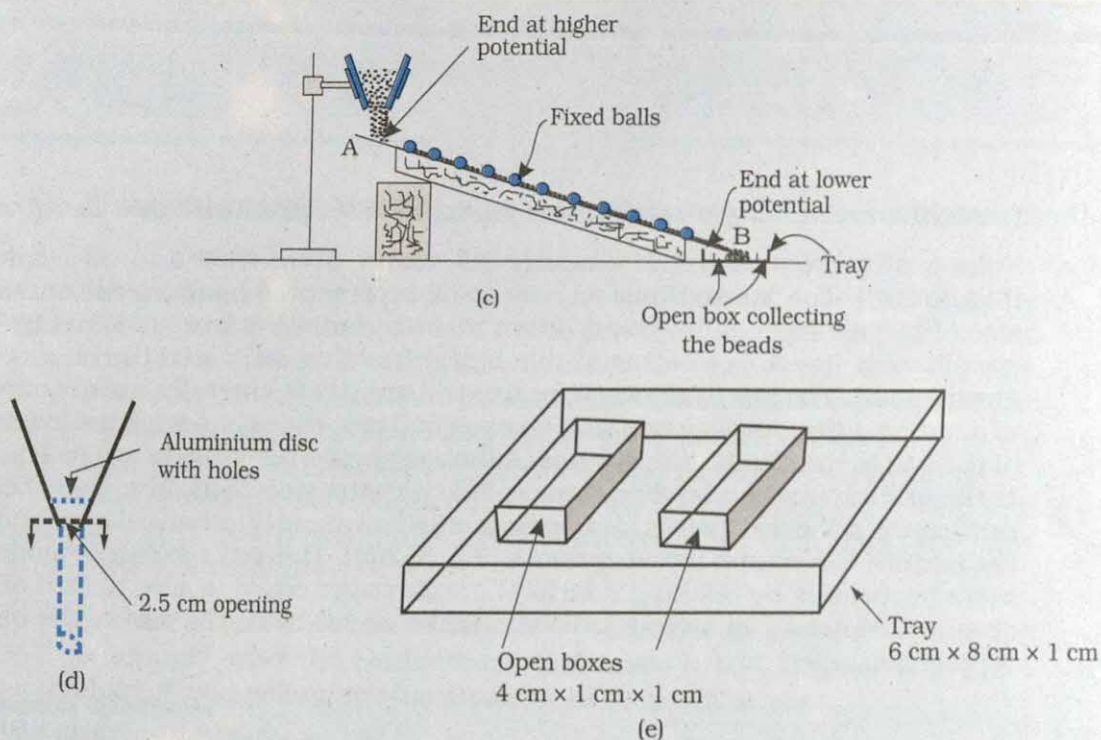


Fig. A_x 2 Making mechanical model of "electron drift" (c) Complete set up of the demonstration (d) Making the device which constantly feeds the small beads at upper end of the channel (e) Open and dry boxes for collecting the beads at lower end of the channel.

To make the base of the channel stable, it is good to fix it over a wooden plank of the same width but 6 cm smaller in length, having a thickness of about 2.5 cm by using a strong adhesive (and not by fixing screws).

For the tiny beads to keep adding at upper end of the channel and colliding with balls and drifting along the channel a suitably modified plastic funnel, filled with beads may be kept close to this end. It may be supported on a ring stand [Fig. A_x 2(c)]. The modification to be done to the funnel is by a way of cutting it carefully so that its lower side has an opening of about 2.5 cm diameter. Inside its lower end is placed a circular aluminium disc with about ten holes in it, which are of size just sufficient to allow one bead each to fall from a hole [Fig. A_x 2(d)]. You would also need a few blocks/wedges, 2 to 3 cm thick, to provide a desired slope to the channel for the tiny balls to keep drifting and colliding with the balls; a tray with a pair of small open boxes would be needed for collecting the beads at the other end of the channel [Fig. A_x 2(e)]. The box filled, say upto 3/4th, with the beads would help in transferring 3 cubic cm of the beads at a time to the end at higher potential, after the other box is kept to collect the beads reaching the end at lower potential.

Resistors and codes to indicate their values

Carbon resistors are made from mixtures of carbon black (a conductor) clay and resin binder (non-conductor). The mixture is pressed and moulded into rods by heating. The resistivity of the mixture depends on the proportion of carbon. The stability of such resistors is poor and their values are usually only accurate to within $\pm 10\%$ but they are cheap, small and good enough for many jobs. The value of a resistor is usually shown by colour markings, as shown in [Fig. A_x 3(a)]. Figures associated with different colours are as under:

TABLE A_x 3.1

Figure	Colour	Figure	Colour
0	Black	5	Green
1	Brown	6	Blue
2	Red	7	Violet
3	Orange	8	Grey
4	Yellow	9	White

The tolerance colours are gold $\pm 5\%$, silver $\pm 10\%$, no colour $\pm 20\%$.

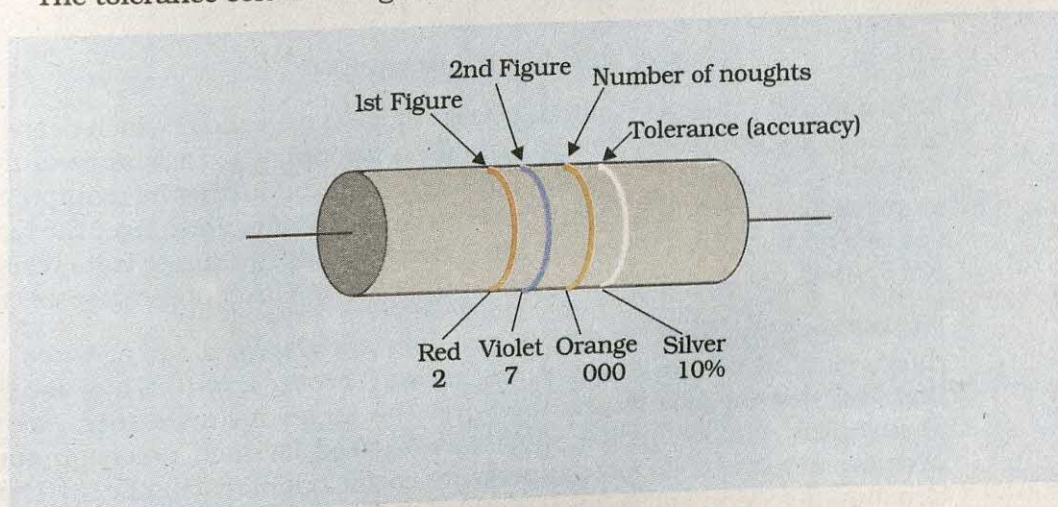


Fig. A_x 3(a) A carbon resistor with colour code marking

This colour code is now being replaced by code with simpler marking, which may be understood by following examples.

TABLE A_x 3.2

Value	0.27Ω	1Ω	3.3Ω	10Ω	220Ω	1000Ω
Mark	R27	1R0	3R3	10R	K22	1K0
Value	1200Ω	68KΩ	100KΩ	1MΩ	6.8MΩ	470KΩ
Mark	1K2	68K	M10	1M0	6M8	M47

In this system the tolerances are indicated by adding a letter:

F = $\pm 1\%$, G = $\pm 2\%$, J = $\pm 5\%$, K = $\pm 10\%$, M = $\pm 20\%$

Examples: 5K6K = 5.6 KΩ $\pm 10\%$

M47J = 470 KΩ $\pm 5\%$

K10F = 100 Ω $\pm 1\%$

Carbon film resistors have recently gained popularity. The stability and accuracy of this type of resistor is commonly $\pm 2\%$ and the power rating 1/8 and 1/2 watt. Its construction is as shown in [Fig. A_x 3(b)].

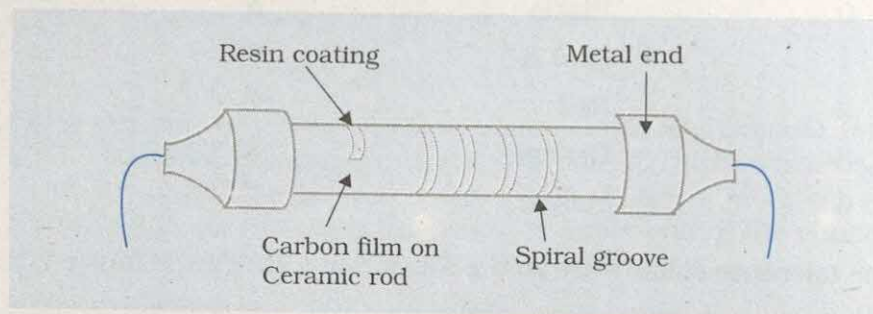


Fig. A_x 3(b) A carbon-film resistor

A ceramic rod is heated to about 1000°C in methane vapour which decomposes and deposits a uniform film of carbon on the rod. The resistance of the film depends on its thickness. Resistance of the film can further be manipulated by increasing it by cutting a spiral groove in it. The thinner and longer the resulting spiral of carbon film connecting the two metal ends, the larger is its resistance. After cutting spiral groove, the film is protected by a layer of epoxy resin coating.

For high accuracy and stability, resistors are always made of wires, as are those required to have a large power rating (i.e. over 2 watt). They use the fact that the thinner and longer the wire, the larger its resistance. Manganin (manganese, copper, nickel alloy) wire is used for high precision standard resistors because of its low temperature coefficient of resistance ($\approx 10^{-5}$ per °C). Constantan (or eureka), an alloy of copper and nickel is used for several purposes (temperature co-efficient $\pm 2 \times 10^{-5}$ per °C, unpredictable). Nichrome (nickel, chromium alloy) wire is used for commercial resistors and heating elements (temperature coefficient 10×10^{-5} p

An improvised open-type fuse holder

To demonstrate the function of a fuse, this type of fuse holder is quite useful in the class room. The fuse wire is quite visible to students against a white background. The burnt out fuse wire can be replaced in just about 5 to 10 seconds.

Take two equal wooden strips each about 5 cm long, 6 mm thick ($1/4$ "), 25 mm broad. Grind one end slightly on a sand paper for tapering each strip. Stick the tapered ends together with a strong adhesive to make an inverted V-shape [Fig. A_x (4)]. On two crocodile clips solder about 1 meter each of flexible electric cable as lead. It should be of 15 A capacity, made of tinned copper wires. Stick the two crocodile clips on the two sloping arms by a strong adhesive (like araldite). The fuse holder is now ready.

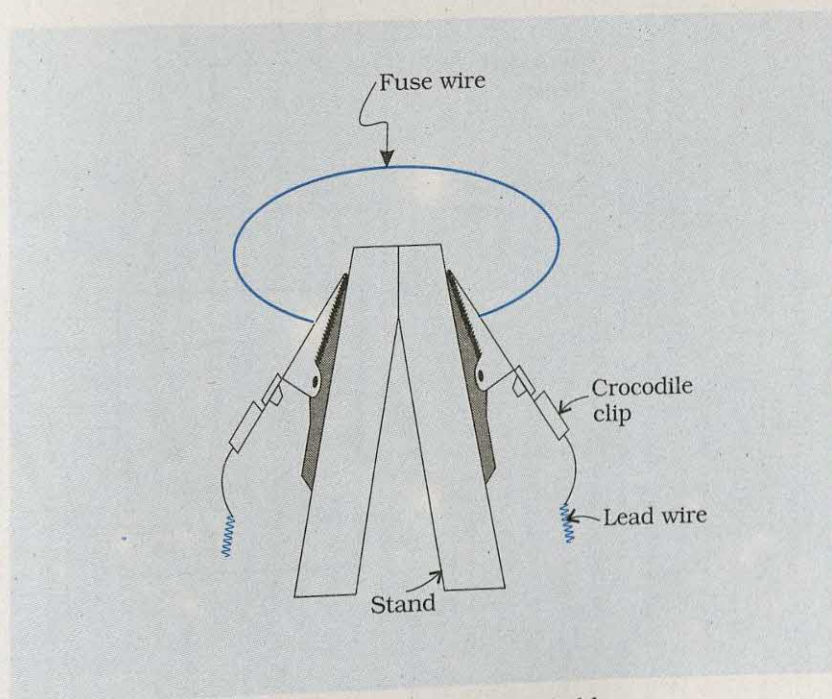
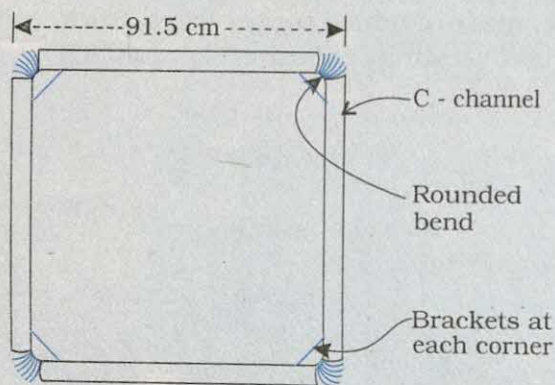


Fig. A_x 4 An open type fuse holder

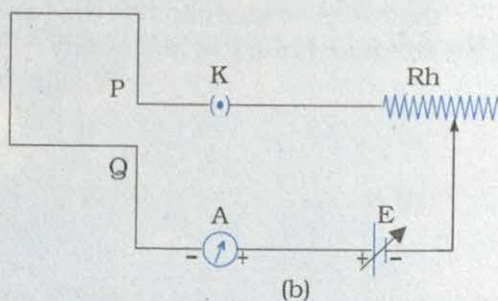
To attach a fuse wire in the fuse holder, take about 12 cm length of fuse wire. On the outer jaw of a crocodile clip, wind two turns of one end of the wire. Similarly, attach other end to the other crocodile clip, leaving a loop of about 5 to 6 cm of wire in the middle.

Making a square coil for study of magnetic field produced by a straight conductor, using only two dry cells as current source

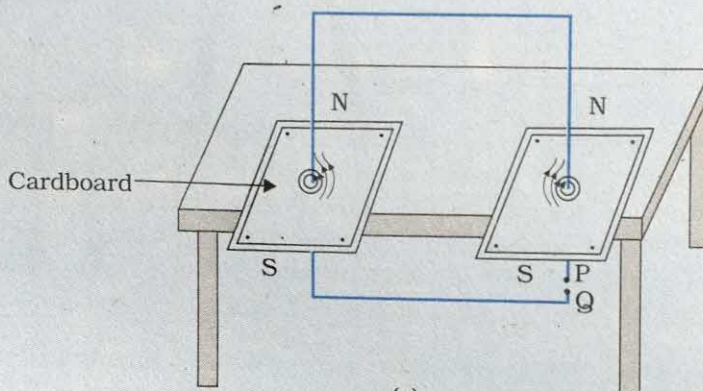
Take an aluminium curtain-channel available in 366 cm length. Make a square of it with each side being $\frac{1}{4}$ th of the total length i.e. 91.5 cm [Fig. A_x 5(a)]. Width of channel should be 6 mm or 9 mm, as is available. Each corner of the square is round. To further strengthen the corners, a 90° bracket of appropriate shape is fixed at each corner.



(a)



(b)



(c)

Fig. A_x 5 Study of magnetic field produced by a straight conductor (a) Large square coil (b) The electric circuit for mapping the magnetic field (c) Mapping the magnetic field due to a straight conductor carrying current using the square coil

In this square wind 40 turns of 24 SWG enamelled copper wire. Resistance of this coil at 20°C is about 11 ohm. Hence even by a battery of 2 dry cells in the common battery box, which gives an emf of 3 V, you may pass a current of upto 250 mA in the coil. This makes total current in all the conductors of one arm taken together equal to 10 amperes, which gives a neutral point at a distance of about 6 cm in the presence of earth's magnetic field. A 12 volt dc power supply or a lead accumulator can be used to supply total current in one arm equal to 40 ampere to demonstrate the field pattern by iron filings.

Fix the coil vertically in the table as shown in [Fig. A_x 5(c)]. Complete the circuit as shown in circuit diagram [Fig. A_x 5(b)]. Let its vertical arm pass through the centres of two horizontal boards fixed on the table. Sprinkle fine iron filings on the cardboards. Pass a current of 1 A in the coil by a 12 volt power supply and tap the cardboards. The iron particles arrange themselves in circular loops around the vertical arms of the coil carrying current.

Making a solenoid for study of its magnetic field

Take copper wire (16 SWG), commonly used for earth connection in domestic electric wiring. Enamelled wire will be better. On a glass bottle of cylindrical shape and diameter between 5 to 5 ½ cm, wind 42 turns of this wire close to each other. When you take it off the bottle, it unwinds by 4 turns, leaving only 38 turns. At the same time, its diameter increases to between 55 mm to 61 mm.

Now take a strip of 6 mm thick plywood, between 16 to 20 cm long and breadth equal to external diameter of the solenoid [Fig. A_x 6(a)]. Along its longer edges, make 1.5 mm deep grooves at 4 mm spacing (i.e. 38 grooves in 152 mm length). Insert it into the solenoid such that its upper surface is the horizontal plane passing through the axis of the solenoid (i.e. height of loops below the lower surface is 6 mm less than height of loops above the upper surface). Put a drop of araldite (or similar adhesive) in each groove and let it harden for 24 hours, thus fixing the solenoid in correct position on the strip.

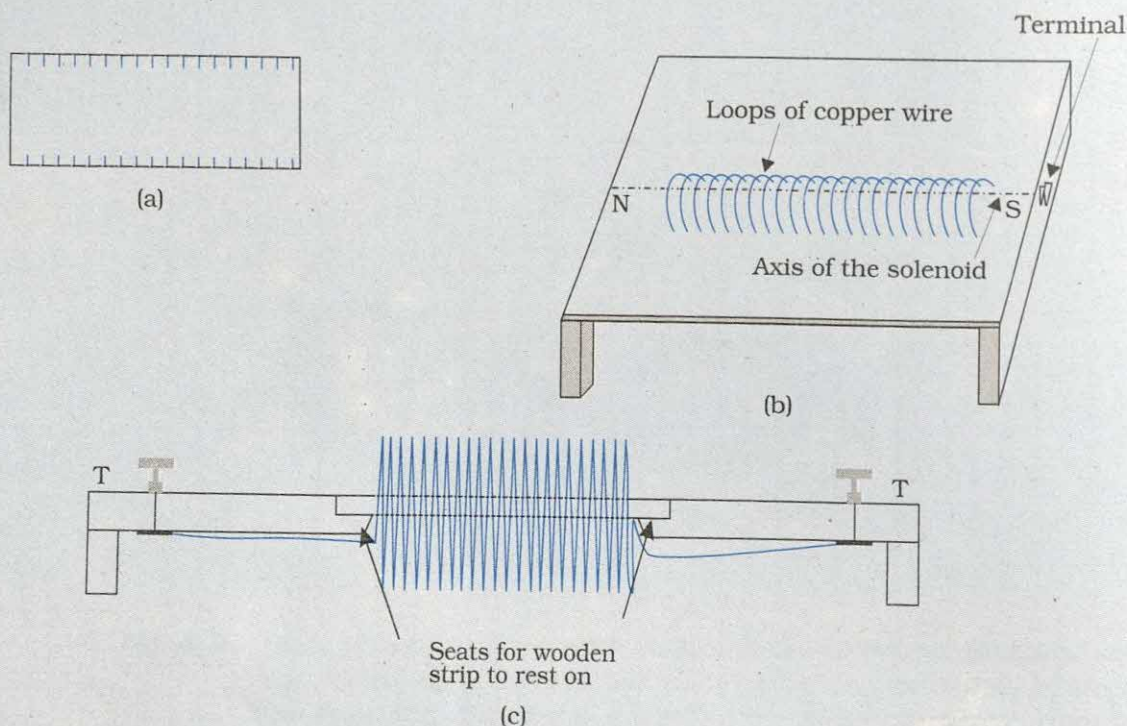


Fig. A_x 6 Solenoid for study of its magnetic field (a) The strip to fix the horizontal plane through its axis (b) Solenoid mounted on a horizontal board (c) Sectional view of the mounted solenoid

Make a wooden board (30 cm × 40 cm) in the centre of which is a window whose size is equal to the wooden strip. At the two ends of this window there are seats for the wooden strip to rest on. Fix the wooden strip on these seats along with solenoid wound on it [Fig. A_x 6(b), (c)]. Fix terminals T, T at the ends of the board and connect the two ends of the solenoid to the terminals.

Your solenoid is ready. Connect the solenoid in series with a rheostat, a key, a battery and an ammeter. You can pass a current 0 to 10A through it and its temperature rises by only 3°C or 4°C above room temperature. Then a magnetic field of 30×10^{-4} T is produced in it, which is enough to demonstrate field pattern by iron filings. You can pass merely 300 mA by a dry cell to plot the field pattern by a plotting compass. A plotting compass can be manipulated inside it by a short length of 16 SWG copper wire, which can be introduced through the 2.5 mm spacing among the turns of the solenoid. You can plot the points inside for mapping the magnetic field by a ball point refill or a short length of pencil lead plugged at the end of the plastic tube of a used ball point refill.

Making a fine slit of uniform width equal to thickness as a razor blade

On a glass sheet of at least 60 mm $\times$ 60 mm, place another glass plate of same size, which has been cut into two parts A and B [(Fig. A_x 7(a))]. A and B separated by a distance equal to thickness of blade C, which stands vertically between them with its sharp edges vertical. Stick end portions of A and B together by adhesive tape so that these are not pushed apart during subsequent work. About 50 mm length of A and B is clear from the adhesive tape [(Fig. A_x 7(b))]. Next place two new blades D and E, one sharp edge of each touching the blade C. Now stick the end portions of D and E together by adhesive tapes T, T.

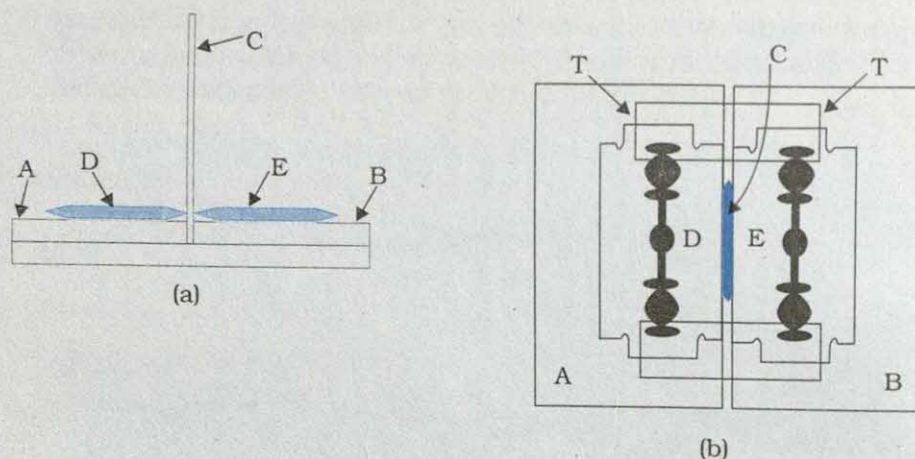


Fig. A_x 7 (a),(b) Making a fine slit of uniform width equal to thickness of a razor blade

Remove blade C and put the assembly of D and E upside down. Fold the extra breadth of tapes T, T on the side which is now upwards. If this assembly is to be made permanent then, instead of folding the adhesive tape, use small pieces of blade coated with a strong adhesive (like araldite) on this side of the assembly. Then this assembly of D and E has a slit of uniform width equal to thickness of blade C and length more than the width of blade C. You can observe diffraction pattern of a clear glass electric bulb preferably with a straight filament with this single slit [refer *Physics Textbook for Class XII Part-II* (NCERT, 2007, p.371)]

Making a simple double slit for Young's experiment

Take a microscope slide. Clean it with soap and water and let it dry. Check that the glass has no ripples visible with naked eyes. (Look at a distant object through it and move it in its own plane. If the distant object is seen shaking, the slide has ripples, and is not made of good glass).

Now paint the slide with graphite colloidal suspension, or black water proof ink used by the artists, or just deposit soot by keeping over a candle flame. Take two razor blades. Hold them together with thumb and fore-finger, close to the corner and make a pair of lines on the slide by this corner. The separation between the two lines, A and B [Fig. A_x 8(a)] is equal to thickness of one blade. If you hold far from this corner, then while drawing the lines, the blade may separate out and separation between the lines may increase at some places, wherever the blades separate out.

You must draw the lines in a single effort and with such a pressure that the glass becomes transparent at the lines. For this reason it is advisable to start with four to five slides, make lines on each and then select the best one by viewing through each at a line source of light. Arrangement shown in [Fig. A_x 8(a)] is helpful for drawing a pair of lines straight and in correct place and direction. The slide S is held between two slightly thicker glass plates P, P. The three are stuck together by an adhesive tape on their lower faces which are in contact with working table. Then a small straight edge E (it can be another glass plate with edge ground or a plastic scale) is supported on the plates PP, so that it remains clear above the coated surface. Then

the pair of lines is drawn by the blades along the edge E.

A slide coated with graphite colloidal suspension or water proof ink may be viewed from any side. However, the slide on which soot is deposited must be held with uncoated side towards the eyes, lest contact with your face may spoil the slide.

In order to be able to see a metre-scale

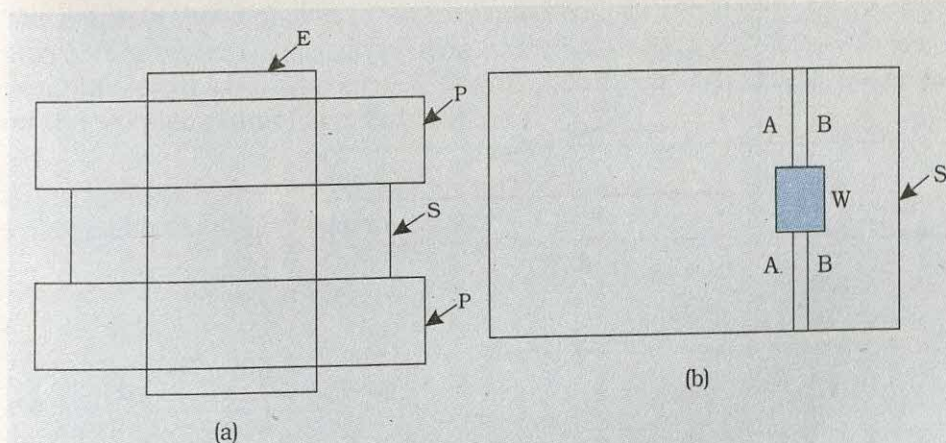


Fig. A_x 8 (a),(b) Making a simple double slit

through it, along with the diffraction pattern, make a clear window, W, of about 5mm × 5mm (or a circle of about 5mm diameter) in the middle of the pair of lines A and B [Fig. A_x 8(b)]. The best way to make the window is to stick a small piece of adhesive tape on the slide before painting it. After painting it, peel off the piece of tape carefully by the tip of a knife. The tape must be of good quality, so that it leaves no spot on the glass after it is peeled off.

Mechanical analogue of scattering of α -particles by atomic nuclei

Principle

The potential at a point of an inverse square force-field (as is that of the nucleus of an atom) is inversely proportional to the distance from the point source of field. If the force is repulsive (as it is between the nucleus and an α -particle), the potential is positive and a graph of h versus r represents the variation of potential with distance [Fig. A_x 9(a)]. If we revolve this curve about the y-axis

[Fig. A_x 9(b)] the solid of revolution of this curve is obtained. Top surface of this

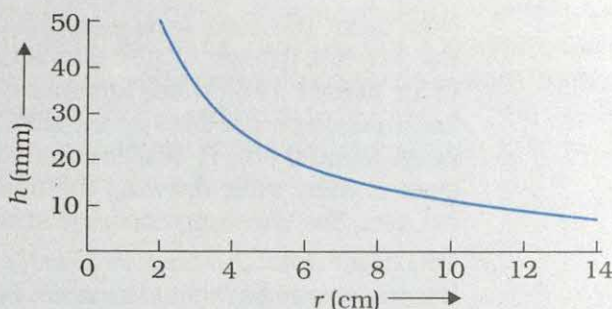


Fig. A_x 9 (a) Variation of potential with distance

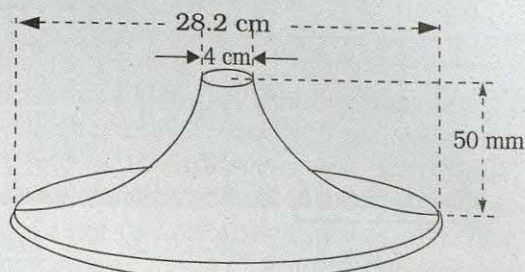
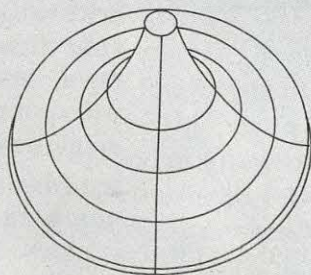
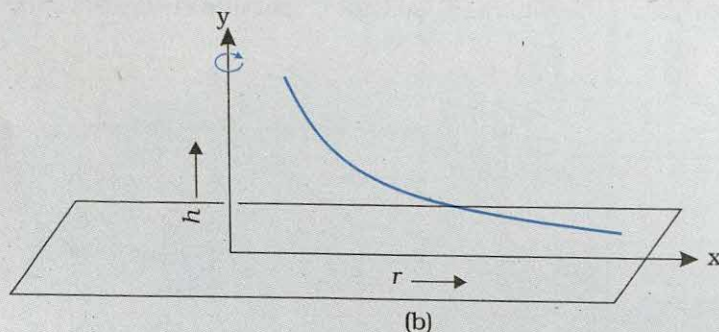


Fig. A_x 9 (b),(c),(d) Mechanical model of a potential hill

solid, the surface of revolution of the curve, gives a mechanical model of the potential hill [Fig. A_x 9(c)]. The potential hill is so constructed that the height h of any point on its surface is proportional to $1/r$, where r is the distance on the plane from the centre.

A ball rolling up this potential hill acquires a gravitational potential energy proportional to h and, therefore, proportional to r . Thus its motion simulates the motion of particle moving in 2-dimensions under a repulsive inverse square force-field. Thus it simulates the motion of a charge moving on the plane in the electric field of the nucleus.

Construction of the Model

A typical model of potential hill can have a base diameter of 28.2 cm, and a top diameter of 4cm and height of 50mm. [Fig. A_x 9(d)]. The model can be turned out of wooden plank 30cm × 30cm × 5cm. First, a curve between h and r [Fig. A_x 9(a)] is drawn on a graph sheet (of size larger than 10 cm × 15 cm) with the following points.

TABLE A_x 9

x (r) cm	14.1	12.5	11.1	10.0	9.0	8.0	7.0
y (h) mm	7.0	8.0	9.0	10.0	11.1	12.5	14.1
	6.0	5.0	4.0	3.3	3.0	2.5	2.0
	16.7	20.0	25.0	30.0	33.3	40.0	50.0

The graph is shown in [Fig. A_x 9(a)] for reference. To make an accurate and smooth curve, it is better to use the instrument "FLEXIBLE CURVE" used by artists. A template is cut to fit this curve. Using this template, the solid of revolution is cut on the wooden plank fixed to a lathe.

Accessories

1. Steel balls of 12.7 mm diameter.

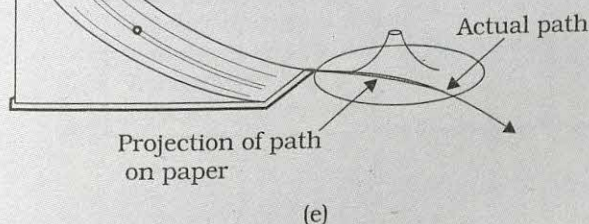


Fig. A_x 9 (e) The ramp is placed along a direction off the centre C

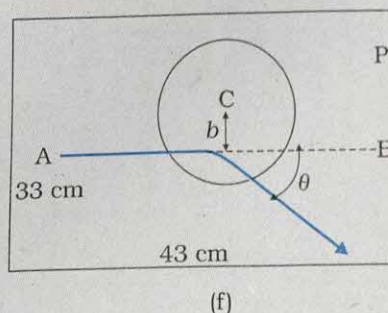


Fig. A_x 9 (f) b is impact parameter

2. A ramp to roll down the balls from different heights (accelerator). A 30 cm plastic scale will be suitable. Height of lower end of ramp must be equal to height of the lower boundary of the potential hill, so that a ball rolling down the ramp smoothly rolls onto the potential hill without any jump. In order that the rolling ball represents high energy α -particles, upper end of the ramp should be of height 12 cm or more. The scale must be fixed in a curved shape, with its lower end horizontal, so that the ball leaving the lower end after rolling down, smoothly rolls on to the potential hill without any significant change in the angle of its motion with respect to horizontal plane.

Experiments with the Potential Hill

In the two experiments described below, the model is to be used as a potential hill to demonstrate the different aspects of alpha scattering. The ramp should be kept with its edge touching the surface of the hill at its lower boundary [Fig. A_x 9(e)]. The ball should be held on the ramp at the desired height with a stopper (a flat scale will do). The ramp should be placed along a direction off the centre C, such as along AB in [Fig. A_x 9(f)]. To trace the path of the ball a paper P, of size 33 cm × 43 cm with a carbon sheet of same size above it is fixed on a large drawing board or plane and smooth table top, which is adjusted horizontal. The model and the ramp can be placed on this paper for both experiments.

Experiment 1: To study dependence of the scattering angle (θ) on the initial energy of the particle.

Release the ball from different heights on the ramp and show that the scattering angle (θ) increases as the initial energy decreases.

Experiment 2: To study the relation between the scattering angle and the impact parameter for a given energy of the alpha particle.

Release the ball from a specified height and determine the scattering angle θ . Measure also the impact parameter b [see Fig. A_x 9(f)]. Repeat the experiment for different values of b but always releasing the ball from the same height. Measure

the scattering angle in each case and show that $b \propto \frac{\cot \theta}{2}$.

DATA SECTION

TABLE D_s 1.1: Some important constants

Name	Symbol	Value
Speed of light in vacuum	c	$2.9979 \times 10^8 \text{ m s}^{-1}$
Charge of electron	e	$1.602 \times 10^{-19} \text{ C}$
Gravitational constant	G	$6.673 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
Planck constant	h	$6.626 \times 10^{-34} \text{ J s}$
Boltzmann constant	k	$1.381 \times 10^{-23} \text{ J K}^{-1}$
Avogadro number	N_A	$6.022 \times 10^{23} \text{ mol}^{-1}$
Universal gas constant	R	$8.314 \text{ J mol}^{-1} \text{ K}^{-1}$
Mass of electron	m_e	$9.110 \times 10^{-31} \text{ kg}$
Mass of neutron	m_n	$1.675 \times 10^{-27} \text{ kg}$
Mass of proton	m_p	$1.673 \times 10^{-27} \text{ kg}$
Electron-charge to mass ratio	e/m_e	$1.759 \times 10^{11} \text{ C/kg}$
Faraday constant	F	$9.648 \times 10^4 \text{ C/mol}$
Rydberg constant	R	$1.097 \times 10^7 \text{ m}^{-1}$
Bohr radius	a_0	$5.292 \times 10^{-11} \text{ m}$
Stefan-Boltzmann constant	σ	$5.670 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$
Wien's constant	b	$2.898 \times 10^{-3} \text{ m K}$
Permittivity of free space	ϵ_0	$8.854 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$
	$1/4\pi\epsilon_0$	$8.987 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$
Permeability of free space	μ_0	$4\pi \times 10^{-7} \text{ T mA}^{-1}$ $\cong 1.257 \times 10^{-6} \text{ Wb A}^{-1} \text{ m}^{-1}$

TABLE D_s 1.2: Other useful constants

Name	Symbol	Value
Mechanical equivalent of heat	J	4.186 J cal^{-1}
Standard atmospheric pressure	1 atm	$1.013 \times 10^5 \text{ Pa}$
Absolute zero	0 K	$-273.15 \text{ }^\circ\text{C}$
Electron volt	1 eV	$1.602 \times 10^{-19} \text{ J}$
Unified Atomic mass unit	1 u	$1.661 \times 10^{-27} \text{ kg}$
Electron rest energy	mc^2	0.511 MeV
Energy equivalent of 1 u	1 uc^2	931.5 MeV
Volume of ideal gas ($0 \text{ }^\circ\text{C}$ and 1 atm)	V	22.4 L mol^{-1}
Acceleration due to gravity (sea level, at equator)	g	9.78049 m s^{-2}

TABLE D_s 2: E. M.F. of cells

Cell	E.M.F. (V)	Cell	E.M.F. (V)
Daniell	1.08 – 1.09	Cadmium at 20°C	1.018 54
Grove	1.8 – 1.9	Lead accumulator	1.9 – 2.2
Lechlanche	1.45	Edison cell	1.45
Voltaic	1.01	Clarke	1.43
Bunsen	1.95	Ni-Fe	1.20

TABLE D_s 3: Refractive index of substances : For sodium light $\lambda = 5896 \times 10^{-10}$ m

Solid	Refractive index	Liquid	Refractive Index
Diamond	2.417	Canada balsam	1.53
Glass (crown)	1.48 – 1.61	Water	1.333
Glass (flint)	1.53 – 1.96	Alcohol (ethyl)	1.362
Glass(soda)	1.50	Aniline	1.595
		Benzene	1.501
Ice	1.31	Cedar oil	1.516
Mica	1.56 – 1.60	Chloroform	1.450
Rock-salt	1.54	Ether	1.350
		Glycerine	1.47
Quartz (O - Ray)	1.5443	Olive oil	1.46
Quartz (E - Ray)	1.5534	Paraffin oil	1.44
Quartz (fused)	1.458	Kerosene oil	1.39
		Turpentine oil	1.44

TABLE D_s 4: Wavelength of spectral lines : (in Å, $1\text{Å} = 10^{-10}$ m)

[The visible spectrum colours are indicated – *r, o, y, g, b, i, v*]

Hydrogen	Helium	Mercury	Neon	Sodium
3970 <i>v</i>	3889 <i>v</i>	4047 <i>v</i>	5765 <i>y</i>	(D ₂) 5890 <i>o</i>
4102 <i>v</i>	4026 <i>v</i>	4078 <i>v</i>	5853 <i>y</i>	(D ₁) 5896 <i>o</i>
4340 <i>b</i>	4471 <i>b</i>	4358 <i>v</i>	5882 <i>o</i>	
4861 <i>gb</i>	5876 <i>y</i>	4916 <i>b, g</i>	6597 <i>r</i>	
6563 <i>r</i>	6678 <i>r</i>	4960 <i>g</i>	7245 <i>r</i>	
	7065 <i>r</i>	5461 <i>g</i>		
		5770 <i>y</i>		
		5791 <i>y</i>		
		6152 <i>o</i>		
		6322 <i>o</i>		

TABLE D_s 5: Electromagnetic spectrum (wavelength)

Range			Wavelength
Wireless waves			5 m and above
Infra-red	3.0×10^{-4} m	to	7.5×10^{-7} m
Visible Red	7.5×10^{-7} m	to	6.5×10^{-7} m
Visible Orange	6.5×10^{-7} m	to	5.9×10^{-7} m
Visible Yellow	5.9×10^{-7} m	to	5.3×10^{-7} m
Visible Green	5.3×10^{-7} m	to	4.9×10^{-7} m
Visible Blue	4.9×10^{-7} m	to	4.2×10^{-7} m
Visible Indigo	4.2×10^{-7} m	to	3.9×10^{-7} m
Ultra Violet	3.9×10^{-7} m	to	1.8×10^{-7} m
Soft X-Rays	2.0×10^{-7} m	to	1.0×10^{-7} m
Hard X-Rays	1.0×10^{-10} m	to	1.0×10^{-11} m
Gamma Rays	5.0×10^{-11} m	to	5.0×10^{-12} m

TABLE D_s 6: Standard Wire Gauges (S.W.G.) and resistances for a metre length of constantan and manganin

S.W.G.		Diameter		Resistance (Ω)	
No.	(mm)	Copper	Constantan (60% Cu, 40% Ni)	Manganin (84% Cu, 4% Ni, 12% Mn)	
10	3.25	0.0021	0.057	0.051	
12	2.64	0.0032	0.086	0.077	
14	2.03	0.0054	0.146	0.131	
16	1.63	0.0083	0.228	0.204	
18	1.22	0.0148	0.405	0.361	
20	0.914	0.0260	0.722	0.645	
22	0.711	0.0435	1.20	1.07	
24	0.559	0.070	1.93	1.73	
26	0.457	0.105	2.89	2.58	
28	0.374	0.155	4.27	3.82	
30	0.315	0.222	6.08	5.45	
32	0.274	0.293	8.02	7.18	
34	0.234	0.404	11.1	9.9	
36	0.193	0.590	16.2	14.5	
38	0.152	0.950	26.0	23.2	
40	0.122	1.48	40.6	36.3	
42	0.102	2.10	58.5	53.4	
44	0.081	3.30	91.4	81.7	
46	0.061	5.90	162.5	145.5	

TABLE D_s 7: Dielectric Constants of Common Materials

Material	Temperature (°C)	Frequency (Hz)	Dielectric Constant
Amber	20	10 ⁶	2.8
Amber	20	3 × 10 ⁹	2.6
Soda glass	20	10 ⁶	7.5
Fused quartz	20	10 ³ to 10 ⁸	3.8
Liquid paraffin (Medical Grade)	20	10 ³	2.2
Transformer oil (Class B)	20	10 ³	2.2
Marble	20	10 ⁶	8
Sand (dry)	20	10 ⁶	3
Sandstone	20	10 ⁶	10
Paper (Oil impregnated condenser tissue)	20	10 ³	2.3
Mica	20	10 ³ to 10 ⁸	5.4 to 7
Epoxy resin (e.g. Araldite)	20	10 ⁶	3.3
Cellulose Acetate	20	10 ⁶	3.5
Vinyl Acetate (Plasticised)	20	10 ⁶	4
Vinyl Chloride (P.V.C.)	20	10 ⁶	4
Ebonite (Pure)	20	10 ⁶	3
Rubber (Vulcanised soft)	20	10 ⁶	3.2
Rubber, Synthetic	20	10 ⁶	2.5
Paraffin wax	20	10 ⁶	2.2
Sulphur	20	3 × 10 ⁹	3.4
Walnut wood (dry)	20	10 ⁷	2.0
Walnut (17% moisture)	20	10 ⁷	5
Vacuum	NA	any	1.00000
Air	20	Upto 3 × 10 ⁹	1.00054
Porcelain	20	10 ⁶	5.5
Barium titanate	20	10 ⁶	1200
Rutile group	20	10 ⁶ to 10 ⁹	40 to 80
Water	20	10 ⁹	80
Water	20	10 ¹⁰	64

TABLE D_s 8: Typical objects with electrostatic charge

Object	C	V	q	Energy $E = \frac{1}{2} C V^2$
1. Balloon of 20cm diameter rubbed all round by nylon cloth	11 pF	200 V	2.2 nC	0.22 μ J*
2. Metal sphere on insulated stand rubbed by silk (dia 9 cm)	5 pF	500 V	2.5 nC	0.62 μ J*
3. Metal sphere charged by a school type Van-de-Graaff generator	5 pF	0.25 MV	1.25 μ C	0.16 J
4. Boy on an insulated stool repeatedly charged by electrophorus	50 pF	3000 V	150 nC	225 μ J*
5. 30 cm $\times$ 30 cm improvised capacitor with wax soaked tissue paper dielectric ($K = 2.7$, $A = 700$ cm and $d = 0.4$ mm) and charged by a 9 V battery.	4 nF	9 V	36 nC	162 nJ*
6. -do- plates separated to 2 cm apart.	80 pF	450 V	36 nC	8.1 μ J*
7. Flash gun capacitors (professional type)	500 pF	400 V	0.2 nC	40 J
8. Average lightning between earth and cloud ($h = 1$ to 5 km)		10^8 V to 10^9 V	20 C	10^9 to 10^{10} J
9. (a) Earth and ionised air of high conductivity at top of stratosphere ($h = 50$ km)	-	0.4 MV	5.7×10^5 C	10^{11} J
(b) Ionisation current between earth and ionosphere in fair weather.	-	0.4 MV	1800 C/s	7×10^8 J/s
10. Charged plate of good electrophorous (diameter 20 to 30 cm) in dry weather, after lifting it up.	10 pF	3000 V	30 nC	45 μ J*

*These bodies in your school laboratory are not dangerous to touch.

TABLE D₉: Electrical resistivities of typical metals and alloys

 Resistivity (10^{-8} ohm metre)

Material	0°C	100°C	300°C	700°C	Temperature coefficient at 0°C (over range 0°C-100°C (10^{-4}))
Aluminium	2.45	3.55	5.9	24.7	45
Chromium	12.7	16.1	25.2	47.2	
Copper	1.56	2.24	3.6	6.7	43
Iron	8.9	14.7	31.5	85.5	65
Lead	19.0	27.0	50	107.6	42
Gold	2.04	2.84			40
Mercury	94.0766*	103.5	128		10
Nickel	6.14	10.33	22.5		68
Platinum	9.81	13.65	21.0	34.3	39.2
Platinum-Rhodium (87/13)	19.0	22.0			15.6
Platinum-Rhodium (90/10)	18.7	21.8			16.6
Platinum-Iridium (90/10)	24.8	28.0			13
Silver	1.51	2.13	3.42	6.5	41
Tin	11.5(20°C)	15.8	50	60	46
Tungsten	4.9	7.3	12.4	24	48
Zinc	5.5	7.8	13.0	37(500°C)	42

Mercury at 0°C is used as a secondary standard to realise the standard unit of resistance, ohm.

TABLE D_s 10: Electrical resistivities of common insulators and semiconductors

Substance	Resistivity (ohm metre)	Substance	(Resistivity (ohm metre)
Diamond	10^{10} to 10^{11}	Carbon 0°C	3.5×10^{-5}
Ebonite	10^{14}	Carbon 500°C	2.7×10^{-5}
Glass (Soda lime)	5×10^9	Carbon 1000°C	2.1×10^{-5}
Glass (Pyrex)	10^{12}	Carbon 2000°C	1.1×10^{-5}
Glass (conducting)	5×10^6	Carbon 2500°C	0.9×10^{-5}
Mica	10^{11} to 10^{15}	Germanium 0°C	0.46
Paper (dry)	10^{10}	Silicon 0°C	2300
Paraffin wax	10^{14}		
Porcelain	10^{10} to 10^{13}		
Sulphur (rhombic)	2×10^{21}		

TABLE D_s : 11 Data for intrinsic and extrinsic semiconductors

Material	Energy Gap (eV)	No. density per m^3 * electron- hole pairs at 300 K	Mobility Electrons ($m^2 V^{-1} s^{-1}$)	Mobility holes ($m^2 V^{-1} s^{-1}$)	Conductivity ($S m^{-1}$)	Density ($kg m^{-3}$)
Semiconductors						
Germanium	0.76	6×10^{19}	0.39	0.19	2.18	5320
Silicon	1.12	7×10^{15}	0.135	0.048	4.4×10^{-4}	2300
Doped Si with P with Insulators	0.045	2.5×10^{21}	0.135	...	2.5×10	2300
Diamond	6 to 12	$\approx 10^7$				

*Values are approximate, they give an idea about order of magnitude only.

TABLE D_s 12: Alloys of high resistance

Alloy	Resistivity 20 °C (10⁻⁸ ohm metre)	Temperature coefficient in range 0-100°C (10⁻⁴)	Max. Operating temp- erature (°C)
Constantan (58.8% Cu, 40% Ni, 1.2% Mn)	44 to 52	- 0.4 to + 0.1	500
German Silver (65% Cu, 20% Zn, 15% Ni)	28 to 35	+ 0.4	150 to 200
Manganin (85% Cu, 12% Mn, 3% Ni)	42 to 48	0.3	100
Nickeline (54% Cu, 20% Zn, 26% Ni)	39 to 45	0.2	150 - 200
Nichrome (67.5% Ni, 15% Cr, 16% Fe, 1.5% Mn)	100 to 110	2.0	1000

TABLE D_s 13: Transition temperature to the superconducting state

Substance	Transition temperature (K)	Substance	Transition temperature (K)
Metals:		Compounds:	
Cadmium	0.6	NiBi	4.2
Zinc	0.8	PbSe	5.0
Aluminium	1.2	NbB	6.0
Uranium	1.3	Nb ₂ C	9.2
Tin	3.7	nBC	10.1 to 10.5
Mercury	4.7	nBN	15 to 16
Lead	7.3	Nb ₃ Sn	18
Niobium	9.2	YBa ₂ Cu ₃ O ₇	90

LOGARITHMS

TABLE I

N	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170						5	9	13	17	21	26	30	34	38
						0212	0253	0294	0334	0374	4	8	12	16	20	24	28	32	36
11	0414	0453	0492	0531	0569						4	8	12	16	20	23	27	31	35
						0607	0645	0682	0719	0755	4	7	11	15	18	22	26	29	33
12	0792	0828	0864	0899	0934						3	7	11	14	18	21	25	28	32
						0969	1004	1038	1072	1106	3	7	10	14	17	20	24	27	31
13	1139	1173	1206	1239	1271						3	6	10	13	16	19	23	26	29
						1303	1335	1367	1399	1430	3	7	10	13	16	19	22	25	29
14	1461	1492	1523	1553	1584						3	6	9	12	15	19	22	25	28
						1614	1644	1673	1703	1732	3	6	9	12	14	17	20	23	26
15	1761	1790	1818	1847	1875						3	6	9	11	14	17	20	23	26
						1903	1931	1959	1987	2014	3	6	8	11	14	17	19	22	25
16	2041	2068	2095	2122	2148						3	6	8	11	14	16	19	22	24
						2175	2201	2227	2253	2279	3	5	8	10	13	16	18	21	23
17	2304	2330	2355	2380	2405						3	5	8	10	13	15	18	20	23
						2430	2455	2480	2504	2529	3	5	8	10	12	15	17	20	22
18	2553	2577	2601	2625	2648						2	5	7	9	12	14	17	19	21
						2672	2695	2718	2742	2765	2	4	7	9	11	14	16	18	21
19	2788	2810	2833	2856	2878						2	4	7	9	11	13	16	18	20
						2900	2923	2945	2967	2989	2	4	6	8	11	13	15	17	19
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	4	5	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6471	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8

LOGARITHMS

TABLE 1 (Continued)

N	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9992	9996	0	1	1	2	2	3	3	3	4

ANTILOGARITHMS

TABLE II

N	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
.00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
.09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
.17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
.20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
.22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
.23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
.27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
.30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
.31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
.37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
.38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	4	5
.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	6
.42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
.45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	4	5	6
.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	4	5	6
.47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	4	5	6
.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	3	4	4	5	6
.49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	3	4	4	5	6

ANTILOGARITHMS

TABLE II (Continued)

N	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
.52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
.58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
.59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
.64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
.72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
.75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
.82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
.84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
.87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

NATURAL SINES

TABLE I

	0'	6'	12'	18'	24'	30'	36'	42'	48'	54'	Mean				
	0°.0	0°.1	0°.2	0°.3	0°.4	0°.5	0°.6	0°.7	0°.8	0°.9	Differences				
											1'	2'	3'	4'	5'
0	.0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	.0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	.0349	0366	0384	0401	0419	0436	0454	0471	0488	0506	3	6	9	12	15
3	.0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	3	6	9	12	15
4	.0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	3	6	9	12	15
5	.0872	0889	0906	0924	0941	0958	0976	0993	1011	1028	3	6	9	12	14
6	.1045	1063	1080	1097	1115	1132	1149	1167	1184	1201	3	6	9	12	14
7	.1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	3	6	9	12	14
8	.1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	3	6	9	12	14
9	.1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	3	6	9	12	14
10	.1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	3	6	9	12	14
11	.1908	1925	1942	1959	1977	1994	2011	2028	2045	2062	3	6	9	11	14
12	.2079	2096	2113	2130	2147	2164	2181	2198	2215	2232	3	6	9	11	14
13	.2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	3	6	8	11	14
14	.2419	2436	2453	2470	2487	2504	2521	2538	2554	2571	3	6	8	11	14
15	.2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	3	6	8	11	14
16	.2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	3	6	8	11	14
17	.2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	3	6	8	11	14
18	.3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	3	6	8	11	14
19	.3256	3272	3289	3305	3322	3338	3355	3371	3387	3404	3	5	8	11	14
20	.3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	3	5	8	11	14
21	.3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	3	5	8	11	14
22	.3746	3762	3778	3795	3811	3827	3843	3859	3875	3891	3	5	8	11	14
23	.3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	3	5	8	11	14
24	.4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	3	5	8	11	13
25	.4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	3	5	8	11	13
26	.4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	3	5	8	10	13
27	.4540	4555	4571	4586	4602	4617	4633	4648	4664	4679	3	5	8	10	13
28	.4695	4710	4726	4741	4756	4772	4787	4802	4818	4833	3	5	8	10	13
29	.4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	3	5	8	10	13
30	.5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	3	5	8	10	13
31	.5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	2	5	7	10	12
32	.5299	5314	5329	5344	5358	5373	5388	5402	5417	5432	2	5	7	10	12
33	.5446	5461	5476	5490	5505	5519	5534	5548	5563	5577	2	5	7	10	12
34	.5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	2	5	7	10	12
35	.5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	2	5	7	10	12
36	.5878	5892	5906	5920	5934	5948	5962	5976	5990	6004	2	5	7	9	12
37	.6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	2	5	7	9	12
38	.6157	6170	6184	6198	6211	6225	6239	6252	6266	6280	2	5	7	9	11
39	.6293	6307	6320	6334	6347	6361	6374	6388	6401	6414	2	4	7	9	11
40	.6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	2	4	7	9	11
41	.6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	2	4	7	9	11
42	.6691	6704	6717	6730	6743	6756	6769	6782	6794	6807	2	4	6	9	11
43	.6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	2	4	6	8	11
44	.6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	2	4	6	8	10

NATURAL SINES

TABLE I (Continued)

	0'	6'	12'	18'	24'	30'	36'	42'	48'	54'	Mean				
	0°.0	0°.1	0°.2	0°.3	0°.4	0°.5	0°.6	0°.7	0°.8	0°.9	Differences				
											1'	2'	3'	4'	5'
45	.7071	7083	7096	7108	7120	7133	7145	7157	7169	7181	2	4	6	8	10
46	.7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	2	4	6	8	10
47	.7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2	4	6	8	10
48	.7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2	4	6	8	10
49	.7547	7558	7570	7581	7593	7604	7615	7627	7638	7649	2	4	6	8	9
50	.7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2	4	6	7	9
51	.7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2	4	5	7	9
52	.7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	2	4	5	7	9
53	.7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2	3	5	7	9
54	.8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	2	3	5	7	8
55	.8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2	3	5	7	8
56	.8290	8300	8310	8320	8329	8339	8348	8358	8368	8377	2	3	5	6	8
57	.8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2	3	5	6	8
58	.8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2	3	5	6	8
59	.8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1	3	4	6	7
60	.8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1	3	4	6	7
61	.8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1	3	4	6	7
62	.8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1	3	4	5	7
63	.8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1	3	4	5	6
64	.8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1	3	4	5	6
65	.9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1	2	4	5	6
66	.9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1	2	3	5	6
67	.9205	9212	9219	9225	9232	9239	9245	9252	9259	9265	1	2	3	4	6
68	.9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1	2	3	4	5
69	.9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1	2	3	4	5
70	.9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1	2	3	4	5
71	.9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1	2	3	4	5
72	.9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1	2	3	3	4
73	.9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1	2	3	3	4
74	.9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1	2	2	3	4
75	.9659	9664	9668	9673	9677	9681	9686	9690	9694	9699	1	1	2	3	4
76	.9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	1	1	2	3	3
77	.9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1	1	2	3	3
78	.9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1	1	2	2	3
79	.9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1	1	2	2	3
80	.9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0	1	1	2	2
81	.9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0	1	1	2	2
82	.9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0	1	1	2	2
83	.9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0	1	1	1	2
84	.9945	9947	9949	9951	9952	9954	9956	9957	9959	9960	0	1	1	1	2
85	.9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0	0	1	1	1
86	.9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0	0	1	1	1
87	.9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0	0	0	1	1
88	.9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0	0	0	0	0
89	.9998	9999	9999	9999	9999	1.000	1.000	1.000	1.000	1.000	0	0	0	0	0
90	1.000														

NATURAL COSINES

TABLE II

	0'	6'	12'	18'	24'	30'	36'	42'	48'	54'	Mean				
	0°.0	0°.1	0°.2	0°.3	0°.4	0°.5	0°.6	0°.7	0°.8	0°.9	Differences				
											1'	2'	3'	4'	5'
0	1.000	1.000	1.000	1.000	1.000	1.000	.9999	.9999	.9999	.9999	0	0	0	0	0
1	.9998	.9998	.9998	.9997	.9997	.9997	.9996	.9996	.9995	.9995	0	0	0	0	0
2	.9994	.9993	.9993	.9992	.9991	.9990	.9990	.9989	.9988	.9987	0	0	0	1	1
3	.9986	.9985	.9984	.9983	.9982	.9981	.9980	.9979	.9978	.9977	0	0	1	1	1
4	.9976	.9974	.9973	.9972	.9971	.9969	.9968	.9966	.9965	.9963	0	0	1	1	1
5	.9962	.9960	.9959	.9957	.9956	.9954	.9952	.9951	.9949	.9947	0	1	1	1	2
6	.9945	.9943	.9942	.9940	.9938	.9936	.9934	.9932	.9930	.9928	0	1	1	1	2
7	.9925	.9923	.9921	.9919	.9917	.9914	.9912	.9910	.9907	.9905	0	1	1	2	2
8	.9903	.9900	.9898	.9895	.9893	.9890	.9888	.9885	.9882	.9880	0	1	1	2	2
9	.9877	.9874	.9871	.9869	.9866	.9863	.9860	.9857	.9854	.9851	0	1	1	2	2
10	.9848	.9845	.9842	.9839	.9836	.9833	.9829	.9826	.9823	.9820	1	1	2	2	3
11	.9816	.9813	.9810	.9806	.9803	.9799	.9796	.9792	.9789	.9785	1	1	2	2	3
12	.9781	.9778	.9774	.9770	.9767	.9763	.9759	.9755	.9751	.9748	1	1	2	3	3
13	.9744	.9740	.9736	.9732	.9728	.9724	.9720	.9715	.9711	.9707	1	1	2	3	3
14	.9703	.9699	.9694	.9690	.9686	.9681	.9677	.9673	.9668	.9664	1	1	2	3	4
15	.9659	.9655	.9650	.9646	.9641	.9636	.9632	.9627	.9622	.9617	1	2	2	3	4
16	.9613	.9608	.9603	.9598	.9593	.9588	.9583	.9578	.9573	.9568	1	2	2	3	4
17	.9563	.9558	.9553	.9548	.9542	.9537	.9532	.9527	.9521	.9516	1	2	3	3	4
18	.9511	.9505	.9500	.9494	.9489	.9483	.9478	.9472	.9466	.9461	1	2	3	4	5
19	.9455	.9449	.9444	.9438	.9432	.9426	.9421	.9415	.9409	.9403	1	2	3	4	5
20	.9397	.9391	.9385	.9379	.9373	.9367	.9361	.9354	.9348	.9342	1	2	3	4	5
21	.9336	.9330	.9323	.9317	.9311	.9304	.9298	.9291	.9285	.9278	1	2	3	4	5
22	.9272	.9265	.9259	.9252	.9245	.9239	.9232	.9225	.9219	.9212	1	2	3	4	6
23	.9205	.9198	.9191	.9184	.9178	.9171	.9164	.9157	.9150	.9143	1	2	3	5	6
24	.9135	.9128	.9121	.9114	.9107	.9100	.9092	.9085	.9078	.9070	1	2	4	5	6
25	.9063	.9056	.9048	.9041	.9033	.9026	.9018	.9011	.9003	.8996	1	3	4	5	6
26	.8988	.8980	.8973	.8965	.8957	.8949	.8942	.8934	.8926	.8918	1	3	4	5	6
27	.8910	.8902	.8894	.8886	.8878	.8870	.8862	.8854		.8838	1	3	4	5	7
28	.8829	.8821	.8813	.8805	.8796	.8788	.8780	.8771	.8763	.8755	1	3	4	6	7
29	.8746	.8738	.8729	.8721	.8712	.8704	.8695	.8686	.8678	.8669	1	3	4	6	7
30	.8660	.8652	.8643	.8634	.8625	.8616	.8607	.8599	.8590	.8581	1	3	4	6	7
31	.8572	.8563	.8554	.8545	.8536	.8526	.8517	.8508	.8499	.8490	2	3	5	6	8
32	.8480	.8471	.8462	.8453	.8443	.8434	.8425	.8415	.8406	.8396	2	3	5	6	8
33	.8387	.8377	.8368	.8358	.8348	.8339	.8329	.8320	.8310	.8300	2	3	5	6	8
34	.8290	.8281	.8271	.8261	.8251	.8241	.8231	.8221	.8211	.8202	2	3	5	7	8
35	.8192	.8181	.8171	.8161	.8151	.8141	.8131	.8121	.8111	.8100	2	3	5	7	8
36	.8090	.8080	.8070	.8059	.8049	.8039	.8028	.8018	.8007	.7997	2	3	5	7	8
37	.7986	.7976	.7965	.7955	.7944	.7934	.7923	.7912	.7902	.7891	2	4	5	7	9
38	.7880	.7869	.7859	.7848	.7837	.7826	.7815	.7804	.7793	.7782	2	4	5	7	9
39	.7771	.7760	.7749	.7738	.7727	.7716	.7705	.7694	.7683	.7672	2	4	6	7	9
40	.7660	.7649	.7638	.7627	.7615	.7604	.7593	.7581	.7570	.7559	2	4	6	8	9
41	.7547	.7536	.7524	.7513	.7501	.7490	.7478	.7466	.7455	.7443	2	4	6	8	10
42	.7431	.7420	.7408	.7396	.7385	.7373	.7361	.7349	.7337	.7325	2	4	6	8	10
43	.7314	.7302	.7290	.7278	.7266	.7254	.7242	.7230	.7218	.7206	2	4	6	8	10
44	.7193	.7181	.7169	.7157	.7145	.7133	.7120	.7108	.7096	.7083	2	4	6	8	10

NATURAL COSINES

TABLE II (Continued)

	0'	6'	12'	18'	24'	30'	36'	42'	48'	54'	Mean				
	0°.0	0°.1	0°.2	0°.3	0°.4	0°.5	0°.6	0°.7	0°.8	0°.9	Differences				
											1'	2'	3'	4'	5'
45	.7071	7059	7046	7034	7022	7009	6997	6984	6972	6959	2	4	6	8	10
46	.6947	6934	6921	6909	6896	6884	6871	6858	6845	6833	2	4	6	8	11
47	.6820	6807	6794	6782	6769	6756	6743	6730	6717	6704	2	4	6	9	11
48	.6691	6678	6665	6652	6639	6626	6613	6600	6587	6574	2	4	7	9	11
49	.6561	6547	6534	6521	6508	6494	6481	6468	6455	6441	2	4	7	9	11
50	.6428	6414	6401	6388	6374	6361	6347	6334	6320	6307	2	4	7	9	11
51	.6293	6280	6266	6252	6239	6225	6211	6198	6184	6170	2	5	7	9	11
52	.6157	6143	6129	6115	6101	6088	6074	6060	6046	6032	2	5	7	9	11
53	.6018	6004	5990	5976	5962	5948	5934	5920	5906	5892	2	5	7	9	12
54	.5878	5864	5850	5835	5821	5807	5793	5779	5764	5750	2	5	7	9	12
55	.5736	5721	5707	5693	5678	5664	5650	5635	5621	5606	2	5	7	10	12
56	.5592	5577	5563	5548	5534	5519	5505	5490	5476	5461	2	5	7	10	12
57	.5446	5432	5417	5402	5388	5373	5358	5344	5329	5314	2	5	7	10	12
58	.5299	5284	5270	5255	5240	5225	5210	5195	5180	5165	2	5	7	10	12
59	.5150	5135	5120	5105	5090	5075	5060	5045	5030	5015	3	5	8	10	13
60	.5000	4985	4970	4955	4939	4924	4909	4894	4879	4863	3	5	8	10	13
61	.4848	4833	4818	4802	4787	4772	4756	4741	4726	4710	3	5	8	10	13
62	.4695	4679	4664	4648	4633	4617	4602	4586	4571	4555	3	5	8	10	13
63	.4540	4524	4509	4493	4478	4462	4446	4431	4415	4399	3	5	8	10	13
64	.4384	4368	4352	4337	4321	4305	4289	4274	4258	4242	3	5	8	11	13
65	.4226	4210	4195	4179	4163	4147	4131	4115	4099	4083	3	5	8	11	13
66	.4067	4051	4035	4019	4003	3987	3971	3955	3939	3923	3	5	8	11	14
67	.3907	3891	3875	3859	3843	3827	3811	3795	3778	3762	3	5	8	11	14
68	.3746	3730	3714	3697	3681	3665	3649	3633	3616	3600	3	5	8	11	14
69	.3584	3567	3551	3535	3518	3502	3486	3469	3453	3437	3	5	8	11	14
70	.3420	3404	3387	3371	3355	3338	3322	3305	3289	3272	3	5	8	11	14
71	.3256	3239	3223	3206	3190	3173	3156	3140	3123	3107	3	6	8	11	14
72	.3090	3074	3057	3040	3024	3007	2990	2974	2957	2940	3	6	8	11	14
73	.2924	2907	2890	2874	2857	2840	2823	2807	2790	2773	3	6	8	11	14
74	.2756	2740	2723	2706	2689	2672	2656	2639	2622	2605	3	6	8	11	14
75	.2588	2571	2554	2538	2521	2504	2487	2470	2453	2436	3	6	8	11	14
76	.2419	2402	2385	2368	2351	2334	2317	2300	2284	2267	3	6	8	11	14
77	.2250	2233	2215	2198	2181	2164	2147	2130	2113	2096	3	6	9	11	14
78	.2079	2062	2045	2028	2011	1994	1977	1959	1942	1925	3	6	9	11	14
79	.1908	1891	1874	1857	1840	1822	1805	1788	1771	1754	3	6	9	11	14
80	.1736	1719	1702	1685	1668	1650	1633	1616	1599	1582	3	6	9	12	14
81	.1564	1547	1530	1513	1495	1478	1461	1444	1426	1409	3	6	9	12	14
82	.1392	1374	1357	1340	1323	1305	1288	1271	1253	1236	3	6	9	12	14
83	.1219	1201	1184	1167	1149	1132	1115	1097	1080	1063	3	6	9	12	14
84	.1045	1028	1011	0993	0976	0958	0941	0924	0906	0889	3	6	9	12	14
85	.0872	0854	0837	0819	0802	0785	0767	0750	0732	0715	3	6	9	12	15
86	.0698	0680	0663	0645	0628	0610	0593	0576	0558	0541	3	6	9	12	15
87	.0523	0506	0488	0471	0454	0436	0419	0401	0384	0366	3	6	9	12	15
88	.0349	0332	0314	0297	0279	0262	0244	0227	0209	0192	3	6	9	12	15
89	.0175	0157	0140	0122	0105	0087	0070	0052	0035	0017	3	6	9	12	15
90	.0000														

NATURAL TANGENTS

TABLE III

	0'	6'	12'	18'	24'	30'	36'	42'	48'	54'	Mean				
	0°.0	0°.1	0°.2	0°.3	0°.4	0°.5	0°.6	0°.7	0°.8	0°.9	Differences				
											1'	2'	3'	4'	5'
0	.0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	.0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	.0349	0367	0384	0402	0419	0437	0454	0472	0489	0507	3	6	9	12	15
3	.0524	0542	0559	0577	0594	0612	0629	0647	0664	0682	3	6	9	12	15
4	.0699	0717	0734	0752	0769	0787	0805	0822	0840	0857	3	6	9	12	15
5	.0875	0892	0910	0928	0945	0963	0981	0998	1016	1033	3	6	9	12	15
6	.1051	1069	1086	1104	1122	1139	1157	1175	1192	1210	3	6	9	12	15
7	.1228	1246	1263	1281	1299	1317	1334	1352	1370	1388	3	6	9	12	15
8	.1405	1423	1441	1459	1477	1495	1512	1530	1548	1566	3	6	9	12	15
9	.1584	1602	1620	1638	1655	1673	1691	1709	1727	1745	3	6	9	12	15
10	.1763	1781	1799	1817	1835	1853	1871	1890	1908	1926	3	6	9	12	15
11	.1944	1962	1980	1998	2016	2035	2053	2071	2089	2107	3	6	9	12	15
12	.2126	2144	2162	2180	2199	2217	2235	2254	2272	2290	3	6	9	12	15
13	.2309	2327	2345	2364	2382	2401	2419	2438	2456	2475	3	6	9	12	15
14	.2493	2512	2530	2549	2568	2586	2605	2623	2642	2661	3	6	9	12	16
15	.2679	2698	2717	2736	2754	2773	2792	2811	2830	2849	3	6	9	13	16
16	.2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	3	6	9	13	16
17	.3057	3076	3096	3115	3134	3153	3172	3191	3211	3230	3	6	10	13	16
18	.3249	3269	3288	3307	3327	3346	3365	3385	3404	3424	3	6	10	13	16
19	.3443	3463	3482	3502	3522	3541	3561	3581	3600	3620	3	7	10	13	16
20	.3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	3	7	10	13	17
21	.3839	3859	3879	3899	3919	3939	3959	3979	4000	4020	3	7	10	13	17
22	.4040	4061	4081	4101	4122	4142	4163	4183	4204	4224	3	7	10	14	17
23	.4245	4265	4286	4307	4327	4348	4369	4390	4411	4431	3	7	10	14	17
24	.4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	4	7	11	14	18
25	.4663	4684	4706	4727	4748	4770	4791	4813	4834	4856	4	7	11	14	18
26	.4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	4	7	11	15	18
27	.5095	5117	5139	5161	5184	5206	5228	5250	5272	5295	4	7	11	15	18
28	.5317	5340	5362	5384	5407	5430	5452	5475	5498	5520	4	8	11	15	19
29	.5543	5566	5589	5612	5635	5658	5681	5704	5727	5750	4	8	12	15	19
30	.5774	5797	5820	5844	5867	5890	5914	5938	5961	5985	4	8	12	16	20
31	.6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	4	8	12	16	20
32	.6249	6273	6297	6322	6346	6371	6395	6420	6445	6469	4	8	12	16	20
33	.6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	4	8	13	17	21
34	.6745	6771	6796	6822	6847	6873	6899	6924	6950	6976	4	9	13	17	21
35	.7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	4	9	13	18	22
36	.7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	5	9	14	18	23
37	.7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	5	9	14	18	23
38	.7813	7841	7869	7898	7926	7954	7983	8012	8040	8069	5	9	14	19	24
39	.8008	8127	8156	8185	8214	8243	8273	8302	8332	8361	5	10	15	20	24
40	.8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	5	10	15	20	25
41	.8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	5	10	16	21	26
42	.9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	5	11	16	21	27
43	.9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	6	11	17	22	28
44	.9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	6	11	17	23	29

NATURAL TANGENTS

TABLE III (Continued)

	0'	6'	12'	18'	24'	30'	36'	42'	48'	54'	Mean				
	0°.0	0°.1	0°.2	0°.3	0°.4	0°.5	0°.6	0°.7	0°.8	0°.9	Differences				
											1'	2'	3'	4'	5'
45	1.0000	0035	0070	0105	0141	0176	0212	0247	0283	0319	6	12	18	24	30
46	1.0355	0392	0428	0464	0501	0538	0575	0612	0649	0686	6	12	18	25	31
47	1-0724	0761	0799	0837	0875	0913	0951	0990	1028	1067	6	13	19	25	32
48	1-1106	1145	1184	1224	1263	1303	1343	1383	1423	1463	7	13	20	27	33
49	1.1504	1544	1585	1626	1667	1708	1750	1792	1833	1875	7	14	21	28	34
50	1-1918	1960	2002	2045	2088	2131	2174	2218	2261	2305	7	14	22	29	35
51	1.2349	2393	2437	2482	2527	2572	2617	2662	2708	2753	8	15	23	30	38
52	1.2799	2846	2892	2938	2985	3032	3079	3127	3175	3222	8	16	24	31	39
53	1.3270	3319	3367	3416	3465	3514	3564	3613	3663	3713	8	16	25	33	41
54	1.3764	3814	3865	3916	3968	4019	4071	4124	4176	4229	9	17	26	34	43
55	1-4281	4335	4388	4442	4496	4550	4605	4659	4715	4770	9	18	27	36	45
56	1-4826	4882	4938	4994	5051	5108	5166	5224	5282	5340	10	19	29	38	48
57	1.5399	5458	5517	5577	5637	5697	5757	5818	5880	5941	10	20	30	40	50
58	1.6003	6066	6128	6191	6255	6319	6383	6447	6512	6577	11	21	32	43	53
59	1.6643	6709	6775	6842	6909	6977	7045	7113	7182	7251	11	23	34	45	56
60	1-7321	7391	7461	7532	7603	7.675	7747	7820	7893	7966	12	24	36	48	60
61	1.8040	8115	8190	8265	8341	8418	8495	8572	8650	8728	13	26	38	51	64
62	1.8807	8887	8967	9047	9128	9210	9292	9375	9458	9542	14	27	41	55	68
63	1.9626	9711	9797	9883	9970	2.0057	2.0145	2.0233	2.0323	2.0413	15	29	44	58	73
64	2.0503	0594	0686	0778	0872	0965	1060	1155	1251	1348	16	31	47	63	78
65	2.1445	1543	1642	1742	1842	1943	2045	2148	2251	2355	17	34	51	68	85
66	2.2460	2566	2673	2781	2889	2998	3109	3220	3332	3445	18	37	55	73	92
67	2.3559	3673	3789	3906	4023	4142	4262	4383	4504	4627	20	40	60	79	99
68	2.4751	4876	5002	5129	5257	5386	5517	5649	5782	5916	22	43	65	87	108
69	2.6051	6187	6325	6464	6605	6746	6889	7034	7179	7326	24	47	71	95	119
70	2.7475	7625	7776	7929	8083	8239	8397	8556	8716	8878	26	52	78	104	131
71	2.9042	9208	9375	9544	9714	9887	3.0061	3.0237	3.0415	3.0595	29	58	87	116	145
72	3.0777	0961	1146	1334	1524	1716	1910	2106	2305	2500	32	64	96	129	161
73	3.2709	2914	3122	3332	3544	3759	3977	4197	4420	4646	36	72	108	144	180
74	3.4874	5105	5339	5576	5816	6059	6305	6554	6806	7062	41	81	122	163	204
75	3.7321	7583	7848	8118	8391	8667	8947	9232	9520	9812	46	93	139	186	232
76	4.0108	0408	0713	1022	1335	1653	1976	2303	2635	2972	53	107	160	213	267
77	4.3315	3662	4015	4374	4737	5107	5483	5864	6252	6646					
78	4.7046	7453	7867	8288	8716	9152	9594	5.0045	5.0504	5.0970	Mean differences cease				
79	5.1446	1929	2422	2924	3435	3955	4486	5026	5578	6140	to be sufficiently accurate.				
80	5.6713	7297	7894	8502	9124	9758	6.0405	6.1066	6.1742	6.2432					
81	6.3138	3859	4596	5350	6122	6912	7720	8548	9395	7.0264					
82	7.1154	2066	3002	3%2	4947	5958	6996	8062	9158	8.0285					
83	8.1443	2636	3863	5126	6427	7769	9152	9.0579	9.2052	9.3572					
84	9.5144	9.677	9.845	10.02	10.20	10.39	10.58	10.78	10.99	11.20					
85	11.43	11.66	11.91	12.16	12.43	12.71	13.00	13.30	13.62	13.95					
86	14.30	14.67	15.06	15.46	15.89	16.35	16.83	17.34	17.89	18.46					
87	19.08	19.74	20.45	21.20	22.02	22.90	23.86	24.90	26.03	27.27					
88	28.64	30.14	31.82	33.69	35.80	38.19	40.92	44.07	47.74	52.08					
89	57.29	63.66	71.62	81.85	95.49	114.6	143.2	191.0	286.5	573.0					
90	not defined														

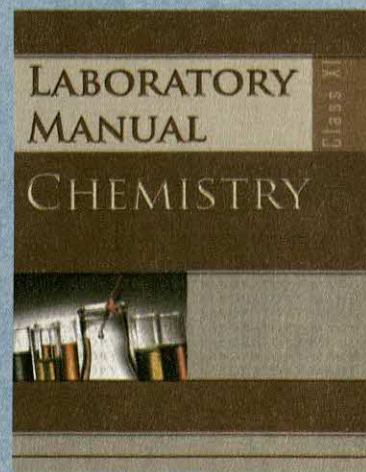
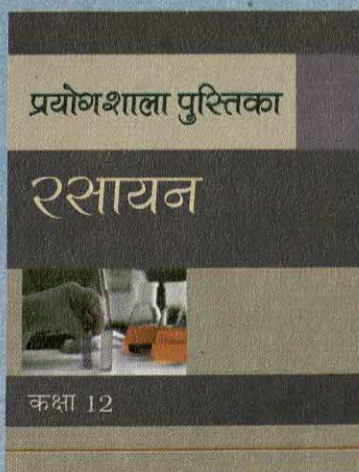
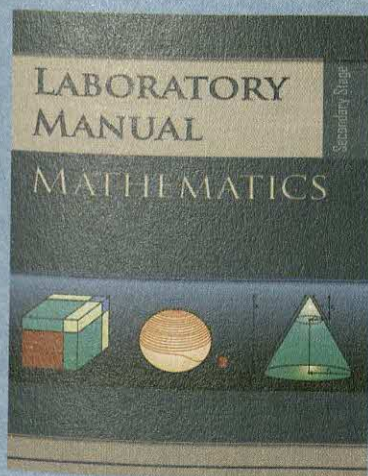
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